

Plant diversity and structural composition of agroforestry systems along the Mount Lawu foothills, Central Java, Indonesia

DINDA SYAFIRA PUTRI¹, DIO MEILANA ARIFIANDITA¹, FAUZAN RAFI WICAKSONO¹,
AGUSTINA PUTRI CAHYANINGSIH², SUGIYARTO², AHMAD DWI SETYAWAN^{1,*}

¹Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./Fax.: +62-271-663375, *email: volatileoils@gmail.com

²Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

Manuscript received: 31 March 2025. Revision accepted: 6 April 2026.

Abstract. Putri DS, Arifiandita DM, Wicaksono FR, Cahyaningsih AP, Sugiyarto, Setyawan AD. 2026. Plant diversity and structural composition of agroforestry systems along the Mount Lawu foothills, Central Java, Indonesia. *Asian J For* 10 (1): r100127. <https://doi.org/10.13057/asianjfor/r100127>. Agroforestry systems play an important role in sustaining biodiversity and ecosystem services in tropical upland landscapes while supporting rural livelihoods. This study assessed plant diversity and structural composition of agroforestry systems along the Mount Lawu foothills, Central Java, Indonesia, to evaluate their ecological characteristics and management implications. Vegetation data were collected from three villages, namely Karangrejo, Ngargoyoso, and Berjo, using a stratified plot design distinguishing tree, pole, and sapling strata. Species composition, vegetation structure, and dominance patterns were analyzed using standard phytosociological parameters, including the Importance Value Index (IVI), while plant diversity was quantified using Shannon-Wiener Diversity (H') and Evenness (E) Indices based on a union species richness approach across strata. A total of 95 plant species were recorded across all sites, with site-level richness ranging from 49 to 66 species, indicating high floristic diversity within smallholder-managed agroforestry systems. All villages exhibited multi-layered vegetation with active regeneration, reflected by the concurrent presence of saplings, poles, and mature trees. IVI analysis showed that a limited number of economically important species, particularly teak (*Tectona grandis*), bamboo (*Dendrocalamus giganteus*), and durian (*Durio zibethinus*), dominated stand structure, with IVI values reaching up to 42.19, highlighting strong management preferences. Despite this dominance, diversity and evenness remained relatively high, with H' values of 3.38-3.76 and E values of 0.86-0.91, indicating balanced community structures and substantial ecological heterogeneity. These findings demonstrate that agroforestry systems in the Mount Lawu foothills support high plant diversity and complex vertical structure while accommodating productive species. The integration of dominant cultivated species with diverse companion plants highlights the role of agroforestry as a sustainable land-use system that balances ecological stability and local livelihood needs. This study provides baseline ecological information to support agroforestry management and biodiversity conservation strategies in upland landscapes of Central Java.

Keywords: Agroforestry, Importance Value Index, Mount Lawu, plant diversity, vegetation structure

INTRODUCTION

Agroforestry systems have long been recognized as multifunctional land-use strategies that integrate woody perennials with agricultural crops and, in some cases, livestock, thereby supporting both production and ecological functions within tropical landscapes (Nair 1993; Jose 2009). In regions experiencing rapid land-use change and agricultural intensification, agroforestry plays a crucial role in maintaining biodiversity, regulating ecosystem processes, and sustaining rural livelihoods. Compared with monoculture systems, agroforestry landscapes often harbor higher plant species richness and structural heterogeneity, which in turn enhance ecosystem services such as soil conservation, microclimate regulation, carbon sequestration, and habitat provision for associated biota (Perfecto and Vandermeer 2010; Tscharnkte et al. 2011; Udawatta et al. 2019). These attributes position agroforestry as a key component of sustainable land management in tropical regions.

Vegetation structure is a fundamental determinant of ecosystem functioning in agroforestry systems. The vertical and horizontal arrangement of plant components influences light interception, nutrient cycling, and competitive interactions among species, ultimately shaping productivity and resilience (Jose 2009). Analyses that explicitly consider growth strata, commonly classified as tree, pole, and sapling layers, provide critical insights into regeneration dynamics, stand stability, and long-term sustainability. The presence of multiple strata reflects ongoing recruitment and management practices, while imbalances among strata may signal overharvesting, insufficient regeneration, or strong dominance by a limited number of species (Magurran 2013; Chazdon 2014). Consequently, stratified vegetation analysis has become an essential approach for evaluating the ecological integrity of managed tropical systems.

Beyond species richness alone, the relative dominance of species within each stratum strongly affects community structure and ecosystem processes. The Importance Value Index (IVI), which integrates relative density, frequency,

and dominance, is widely used to identify ecologically and functionally dominant species in forest and agroforestry systems (Curtis and McIntosh 1951; Mueller-Dombois and Ellenberg 1974). IVI-based assessments allow researchers to distinguish between systems characterized by balanced species contributions and those dominated by a few economically favored taxa. Such dominance patterns are particularly relevant in agroforestry landscapes, where management decisions often prioritize timber, fruit, or multipurpose species, potentially reshaping vegetation structure over time (Kumar and Nair 2004; Jose 2009).

The foothills of Mount Lawu, Central Java, Indonesia, represent a dynamic agroforestry landscape where smallholder-managed systems form a mosaic of production-oriented and conservation-relevant land uses. Situated along an altitudinal gradient and adjacent to forested areas, agroforestry plots in this region incorporate a mixture of timber species, fruit trees, and understory crops that reflect both traditional knowledge and market-driven preferences. These systems contribute to household income while simultaneously buffering surrounding natural habitats from further agricultural expansion. However, increasing pressure from population growth and commercialization raises concerns regarding structural simplification and the potential erosion of biodiversity within these agroforestry systems (Hairiah et al. 2011; van Noordwijk et al. 2014).

Despite the recognized importance of agroforestry in Java, quantitative studies that integrate detailed vegetation structure with IVI-based dominance analysis remain limited, particularly in upland and foothill environments. Previous research in Indonesian agroforestry landscapes has often emphasized species inventories or socioeconomic aspects, with less attention given to how structural composition across growth strata reflects management intensity and sustainability (Hairiah et al. 2011; Nair and Garrity 2012). Moreover, few studies have explicitly compared multiple sites within the same mountainous landscape using standardized plot designs and stratified

analyses, limiting the ability to draw broader ecological inferences.

In this context, the present study question of whether smallholder agroforestry systems along the foothills of Mount Lawu, Java, support high plant species diversity and complex vegetation structure across different growth strata. Specifically, it investigates how species composition, diversity indices, and importance value patterns vary among tree, pole, and sapling strata, and whether dominant cultivated species coexist with diverse companion plants within these systems. Accordingly, this study addresses the following questions: (i) How do species composition and richness vary among agroforestry sites along the Mount Lawu foothills? (ii) How is vegetation structure distributed across tree, pole, and sapling strata, and what does this reveal about regeneration and management patterns? (iii) Which species dominate each stratum based on IVI, and how do dominance patterns differ among sites? By combining diversity indices with IVI-based structural analysis, this study seeks to provide a comprehensive ecological evaluation of agroforestry systems in a tropical montane landscape and to contribute empirical evidence supporting sustainable agroforestry management in Java and comparable regions.

MATERIALS AND METHODS

Study area

The study was conducted in three villages, namely Karangrejo, Ngargoyoso, and Berjo, located along the foothills of Mount Lawu, Central Java, Indonesia (Figure 1). Mount Lawu is a prominent volcanic mountain forming part of the southern mountain range of Java and represents an important ecological transition zone between lowland agricultural areas and montane forest ecosystems. The selected villages are situated on the western and southern slopes of the mountain and are characterized by extensive smallholder-managed agroforestry systems that dominate the local landscape.

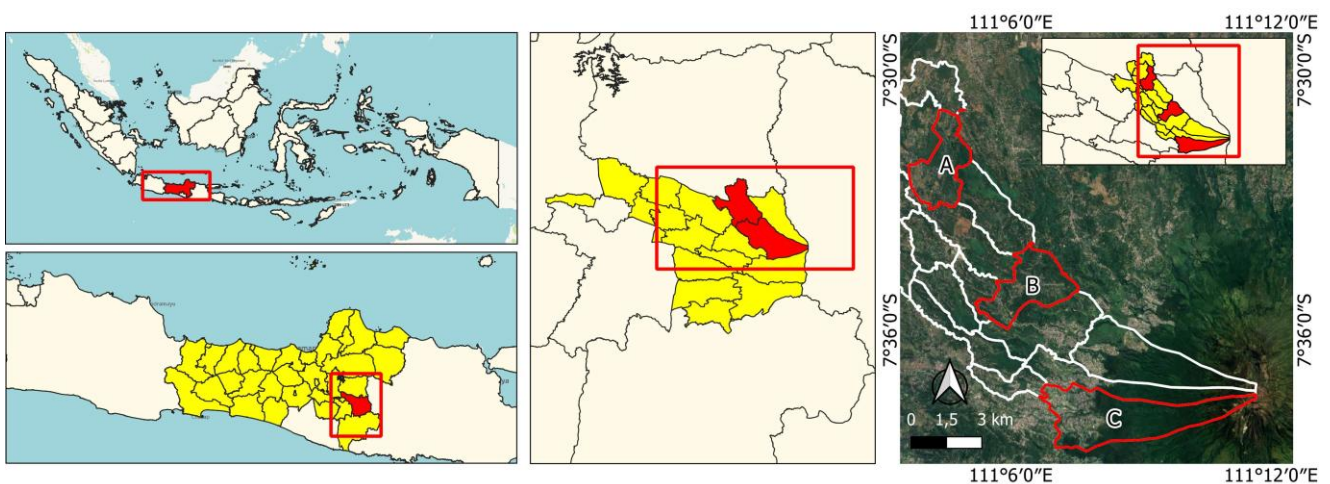


Figure 1. Location of the study sites in Karanganyar District, Central Java Province, Indonesia. A. Karangrejo Village, B. Ngargoyoso Village, C. Berjo Village

The study area lies at an elevation ranging approximately from 600 to 1,200 m above sea level, with variations among villages reflecting local topography and slope position. The region experiences a tropical monsoon climate, with a distinct wet season typically occurring from November to March and a dry season from April to October. Mean annual rainfall generally exceeds 2,000 mm, while average temperatures decrease with elevation, creating relatively cool and humid conditions favorable for diversified perennial-based land-use systems (Whitten et al. 1996; Aldrian and Susanto 2003). These climatic conditions support the coexistence of timber trees, fruit-bearing species, and understory crops within agroforestry plots.

Land use in Karangrejo, Ngargoyoso, and Berjo is dominated by agroforestry and mixed gardens, locally known as *tegalan* or *kebun campuran*, interspersed with settlement areas and patches of production forest. Agroforestry systems in this region typically integrate timber species such as teak (*Tectona grandis*), bamboo (*Dendrocalamus* spp.), and mahogany (*Swietenia* spp.) with fruit trees and annual or semi-perennial crops. Management practices vary among households, ranging from relatively intensive systems focused on market-oriented species to more diverse, traditionally managed plots that emphasize subsistence production and risk buffering (Hairiah et al. 2011; Nair and Garrity 2012).

The proximity of the study sites to remaining forest areas and protected zones around Mount Lawu enhances the ecological significance of these agroforestry systems. They function not only as production units but also as buffer zones that potentially reduce pressure on natural forests and contribute to landscape-level biodiversity conservation (van Noordwijk et al. 2014). This combination of biophysical heterogeneity, traditional management, and conservation relevance makes the Mount Lawu foothills a suitable setting for examining plant diversity and vegetation structure in tropical agroforestry systems.

Sampling design and vegetation data collection

Vegetation data were collected using a stratified plot-based sampling design commonly applied in forest and agroforestry studies to capture vertical structure and regeneration dynamics. Sampling plots were established within agroforestry fields in each study village (Karangrejo, Ngargoyoso, and Berjo) and were positioned to represent dominant land-use types and management conditions at each site. Plot placement followed a purposive–systematic approach to ensure adequate representation of spatial heterogeneity while maintaining comparability among locations (Mueller-Dombois and Ellenberg 1974; Kent 2012). The overall plot configuration and nesting scheme are illustrated in Figure 2.

Within each sampling plot, vegetation was classified into three growth strata based on Diameter at Breast Height (DBH): tree, pole, and sapling strata. The tree stratum comprised woody individuals with $DBH \geq 20$ cm, representing mature canopy components. The pole stratum included individuals with DBH between 10 and <20 cm,

reflecting intermediate growth stages and potential future canopy recruits. Saplings consisted of woody individuals with $DBH < 10$ cm and a minimum height threshold, representing early regeneration and understory components. This stratified approach enables assessment of both current stand structure and regeneration dynamics within agroforestry systems (Magurran 2013; Chazdon 2014).

Different plot sizes were applied to each vegetation stratum to account for differences in plant size and spatial distribution. Larger plots were used for tree measurements to adequately capture canopy-level species, while progressively smaller nested subplots were established for pole and sapling strata. Diameter at breast height was measured at 1.3 m above ground using a diameter tape, following standard forestry procedures. For individuals with irregular stems or buttresses, DBH measurements were adjusted according to established guidelines to ensure consistency and comparability (Philip 1994; Kent 2012).

All woody plant species encountered within the sampling plots were identified to species level whenever possible using field characteristics and local ecological knowledge. Scientific names were subsequently verified using standard taxonomic references and updated nomenclature to minimize identification errors. The number of individuals per species was recorded separately for each vegetation stratum, forming the basis for subsequent analyses of vegetation structure, dominance, and community composition.

Although the number of plots and total sampled area varied slightly among villages due to differences in agroforestry plot size and landscape configuration, sampling procedures and stratification criteria were applied consistently across all sites. This standardized sampling design ensures that vegetation data accurately represent species composition and structural characteristics of agroforestry systems along the Mount Lawu foothills.

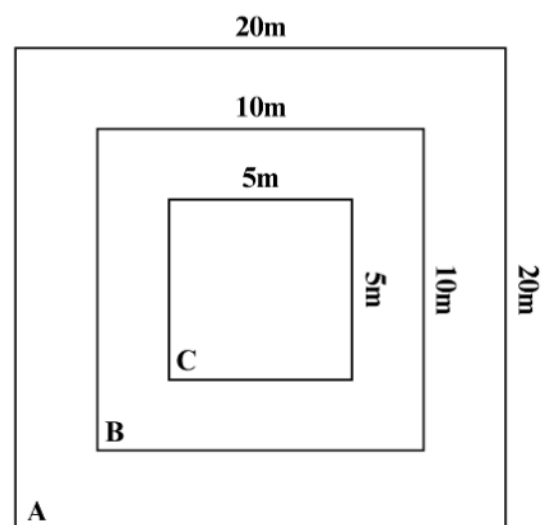


Figure 2. Schematic diagram of sampling plot design. A. Tree, B. Pole, C. Sapling

Vegetation structure and importance value analysis

Vegetation structure was analyzed separately for each growth stratum (tree, pole, and sapling) to characterize species composition, dominance patterns, and regeneration status within agroforestry systems. For each stratum, basic structural attributes were quantified, including density, frequency, and dominance, following standard phytosociological procedures (Mueller-Dombois and Ellenberg 1974; Kent 2012). These parameters provide complementary information on species abundance, spatial distribution, and relative contribution to stand structure.

Species density was calculated as the number of individuals of a given species per unit area within each stratum. Relative density was then obtained by expressing the density of each species as a percentage of the total density of all species in the same stratum. Frequency was calculated as the proportion of plots in which a species occurred relative to the total number of plots, while relative frequency was derived by dividing the frequency of a species by the sum of frequencies of all species. These metrics describe how evenly species are distributed across the sampled area.

Dominance was assessed based on basal area, calculated from Diameter at Breast Height (DBH) measurements for each individual using standard geometric relationships. Basal area values were summed by species and expressed per unit area. Relative dominance was obtained by dividing the basal area of a species by the total basal area of all species within the same stratum. Basal area-based dominance is particularly relevant for tree and pole strata, as it reflects space occupancy and competitive influence within the stand (Philip 1994; Chazdon 2014).

The Importance Value Index (IVI) was calculated for each species within each stratum as the sum of relative density, relative frequency, and relative dominance. IVI values thus range from 0 to 300 and provide an integrated measure of the ecological importance of species in the community (Curtis and McIntosh 1951; Mueller-Dombois and Ellenberg 1974). By combining multiple structural attributes, IVI allows the identification of dominant species that shape overall vegetation structure and function.

Analyses were conducted separately for tree, pole, and sapling strata to avoid bias arising from differences in size, life stage, and ecological role among growth forms. Pooling individuals across strata can obscure regeneration patterns and overemphasize mature canopy species, particularly in managed systems such as agroforestry. Stratified analysis enables clearer interpretation of management effects on stand structure, recruitment dynamics, and long-term sustainability (Kumar and Nair 2004; Magurran 2013). This approach provides a robust framework for comparing structural composition among sites along the Mount Lawu foothills.

Diversity and evenness indices

Plant diversity within agroforestry systems was quantified using the Shannon-Wiener Diversity Index (H'), which incorporates both species richness and the relative abundance of individuals among species. The index was calculated for each study site based on the proportion of

individuals of each species relative to the total number of individuals recorded. Shannon-Wiener diversity is widely applied in ecological studies of managed and natural vegetation because it is sensitive to changes in both rare and dominant species (Shannon and Weaver 1949; Magurran 2013).

Species evenness (E) was calculated to assess how evenly individuals were distributed among species within each site. Evenness was derived by dividing the observed Shannon-Wiener Diversity Index by the maximum possible diversity for a given number of species, expressed as the natural logarithm of species richness. Values of E range from 0 to 1, with higher values indicating a more equitable distribution of individuals among species. Together, H' and E provide complementary insights into community organization and stability beyond species counts alone (Pielou 1966; Magurran 2013).

Species richness was calculated using a union-based approach across growth strata (tree, pole, and sapling). Under this approach, each species was counted only once per site, regardless of its occurrence in multiple strata. This method avoids artificial inflation of species richness that can occur when species are tallied separately by growth stage and subsequently summed. The union approach is particularly appropriate for stratified vegetation studies in agroforestry systems, where many species may be present simultaneously as saplings, poles, and mature trees (Kent 2012; Chazdon 2014).

By combining union-based species richness with Shannon-Wiener Diversity and Evenness Indices, this study provides a robust assessment of plant diversity patterns across agroforestry sites along the Mount Lawu foothills while maintaining methodological consistency with stratified structural analyses.

Data analysis

Data analyses were conducted using a comparative approach to evaluate differences in plant diversity and vegetation structure among the three study sites (Karangrejo, Ngargoyoso, and Berjo). Structural attributes, diversity indices, and Importance Value Index (IVI) were calculated separately for each site and vegetation stratum, allowing site-level comparisons without pooling data across locations. This approach enables the identification of spatial variation in agroforestry composition and structure along the Mount Lawu foothills while maintaining consistency in analytical procedures.

Results are presented using a combination of tables and figures selected to emphasize clarity and interpretability. Tables were used to summarize quantitative metrics such as species richness, diversity indices, and IVI values, providing detailed numerical information for each site and stratum. Figures were employed to visualize key patterns, including differences in diversity and species dominance among sites. Visualizations were designed to avoid redundancy with tables and to highlight comparative trends rather than replicate raw data.

All figures were prepared using consistent graphical standards, including uniform axis labels, scales, and formatting, to facilitate cross-site comparison. Species

names in figures were abbreviated at the genus level after first mention, following standard taxonomic conventions. This data presentation strategy ensures that results are communicated clearly and effectively, supporting robust interpretation in subsequent sections.

RESULTS AND DISCUSSION

Species composition and richness across sites

A total of 95 plant species belonging to 39 families were recorded across the three agroforestry sites along the Mount Lawu foothills, indicating high floristic diversity within smallholder-managed systems. Species richness varied among villages, with Berjo recording the highest number of species (66 species, 39 families), followed by Ngargoyoso (52 species, 28 families) and Karangrejo (49 species, 25 families). Each village was surveyed using 10 sampling plots, ensuring comparable sampling effort across sites. This spatial variation reflects heterogeneity in agroforestry composition that is likely influenced by differences in management intensity, land-use history, and landscape context, including proximity to remnant forested areas (Table 1 and Figure 3).

Analysis of species occurrence across vegetation strata showed that many species were present simultaneously in more than one growth stage, occurring as saplings, poles, and mature trees. This cross-stratum occurrence indicates active regeneration processes and continuous recruitment within the agroforestry systems. In contrast, several species were restricted to a single stratum, suggesting either early establishment phases or selective retention of mature individuals depending on management objectives. To avoid overestimation of species richness, a union-based approach was applied, whereby each species was counted once per site regardless of its occurrence across multiple strata, ensuring consistent and comparable richness estimates among villages.

Clear patterns of species uniqueness were also observed among the study sites. Berjo exhibited the highest number of site-specific species, contributing to its greater overall richness, whereas Karangrejo and Ngargoyoso shared a larger proportion of taxa. This pattern suggests that agroforestry systems along the Mount Lawu foothills form a mosaic of shared and locally distinctive plant assemblages shaped by site-specific management practices and environmental conditions.

In addition to overall richness, species composition across sites was characterized by the recurrent presence of a limited number of dominant species. Economically important timber, fruit, and multipurpose species were consistently recorded and often occurred across multiple strata, reflecting deliberate cultivation and long-term retention by farmers. Despite differences in species richness, all sites exhibited relatively high diversity and moderate evenness, with Shannon-Wiener Diversity Index (H') values ranging from 3.38 to 3.76 and evenness (E) values from 0.86 to 0.91, indicating structurally complex plant communities. The coexistence of dominant economic species with a diverse pool of subordinate taxa underscores

the dual production–conservation function of agroforestry systems in the Mount Lawu foothills.

Vegetation structure by growth strata

The vertical structure of agroforestry vegetation across the Mount Lawu foothills was characterized by the distribution of individuals among tree, pole, and sapling strata, revealing clear differences among the three study sites (Table 2 and Figure 4). Across all villages, a total of 1,915 individuals were recorded, indicating structurally complex and multi-layered agroforestry systems that integrate mature woody components with intermediate growth stages and active regeneration.

At the tree stratum, the abundance of mature individuals varied among villages. Karangrejo supported 141 tree individuals, Ngargoyoso recorded 92 individuals, and Berjo contained 140 individuals, indicating stronger retention of mature canopy components in Karangrejo and Berjo. These differences suggest variation in long-term management objectives, with some sites emphasizing the persistence of timber and perennial species, while others may adopt more frequent harvesting or replacement cycles.

The pole stratum formed an important transitional layer linking sapling recruitment with the mature tree canopy. Ngargoyoso exhibited the highest number of pole individuals (99), followed by Karangrejo (97) and Berjo (79). The relatively strong pole component in Ngargoyoso indicates an actively developing stand structure with a substantial pool of intermediate-sized individuals that may contribute to future canopy formation.

Table 1. Characteristics of plant communities across agroforestry sites

Parameter	Village		
	Karangrejo	Ngargoyoso	Berjo
Total Plot	10	10	10
Total Family	25	28	39
Total Species	49	52	66
Species Diversity Index (H')	3.38 (High)	3.43 (High)	3.76 (High)
Evenness Index (E)	0.87 (Medium)	0.86 (Medium)	0.91 (Medium)

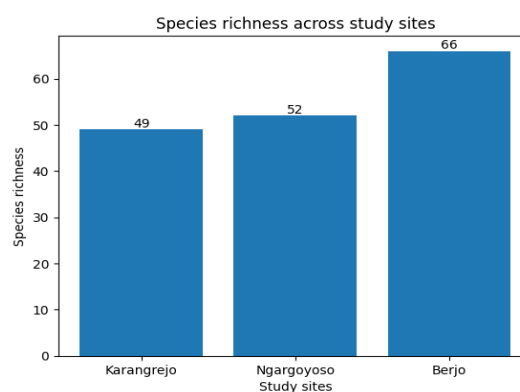
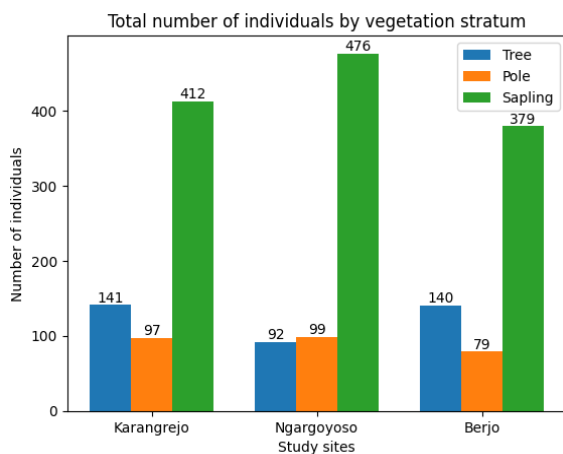


Figure 3. Species richness across study sites

Table 2. Sampling effort and vegetation structure of agroforestry systems along the Mount Lawu foothills, Central Java, Indonesia

Parameter	Karangrejo Village	Ngargoyoso Village	Berjo Village
Number of sampling plots	10	10	10
Plot size-Tree stratum (m ²)	20×20 (400)	20×20 (400)	20×20 (400)
Plot size-Pole stratum (m ²)	10×10 (100)	10×10 (100)	10×10 (100)
Plot size-Sapling stratum (m ²)	5×5 (25)	5×5 (25)	5×5 (25)
Total sampled area per site (m ²)	4,000	4,000	4,000
Number of tree individuals	141	92	140
Number of pole individuals	97	99	79
Number of sapling individuals	412	476	379
Total number of individuals	650	667	598

**Figure 4.** Total number of individuals by vegetation stratum

Saplings constituted the most abundant growth stratum across all sites, underscoring the importance of regeneration processes within agroforestry systems. Sapling abundance reached 412 individuals in Karangrejo, 476 in Ngargoyoso, and 379 in Berjo, reflecting continuous establishment of new plants through deliberate planting and natural recruitment. Variation in sapling abundance among villages suggests differences in planting intensity, shade tolerance of cultivated species, and understory management practices such as weeding and thinning.

Comparative analysis of vertical structure highlights contrasting structural profiles among sites. Berjo displayed a relatively balanced distribution across tree, pole, and sapling strata, indicating a stable and well-developed agroforestry stand. Ngargoyoso was characterized by high numbers of saplings and poles, suggesting an actively expanding system with strong recruitment potential. In contrast, Karangrejo showed a structure dominated by saplings with fewer mature trees relative to total individuals, reflecting a more dynamic or recently modified agroforestry configuration.

The observed variation in vegetation structure across growth strata indicates that agroforestry systems along the Mount Lawu foothills represent a spectrum of stand development stages shaped by local management practices and objectives. These stratified structural patterns provide a critical foundation for interpreting species dominance, diversity patterns, and ecosystem functioning in subsequent analyses.

Dominant species based on Importance Value Index (IVI)

Patterns of species dominance across agroforestry sites were clearly reflected by Importance Value Index (IVI) values, highlighting the structural and functional roles of key species within each vegetation stratum (Tables 3-5, Figure 5). Across all sites, dominance was concentrated in a small number of economically important woody species, indicating strong management preferences and selective retention within agroforestry systems.

At Karangrejo, the tree stratum was dominated by *T. grandis* with an IVI of 25.10, followed by *Dendrocalamus giganteus* (22.89) and *Durio zibethinus* (22.49). In the pole stratum, *D. giganteus* also showed strong dominance (22.89), while *D. zibethinus* remained prominent (22.49), indicating continuity of dominant species across growth stages. This pattern suggests deliberate cultivation and long-term retention of timber and fruit species that contribute both to canopy structure and household income.

At Ngargoyoso, dominance patterns were more pronounced. *Dendrocalamus giganteus* overwhelmingly dominated the tree stratum with an IVI of 42.19, followed by *D. zibethinus* (38.27), while *T. grandis* showed lower dominance (16.38). The high IVI values of bamboo and fruit trees indicate intensive management favoring fast-growing, multipurpose species that provide construction material, food, and rapid economic returns. The dominance of these taxa across strata reflects an actively managed agroforestry system with strong production orientation.

At Berjo, *D. giganteus* again emerged as the most dominant tree species with an IVI of 33.15, followed by *T. grandis* (20.25) and *Azadirachta indica* (15.98). Compared to the other sites, dominance in Berjo was more evenly distributed among species, suggesting a structurally balanced system that integrates timber, bamboo, and multipurpose trees. This balanced dominance pattern aligns with the more even vertical structure observed at this site.

The dominance of *T. grandis*, *D. giganteus*, and *D. zibethinus* across sites underscores the strong influence of farmer management decisions in shaping species composition and structural hierarchy. High IVI values of these species reflect their combined ecological importance and socio-economic value, reinforcing the role of agroforestry systems along the Mount Lawu foothills as production-oriented landscapes that simultaneously maintain structural complexity and functional diversity.

Table 3. Importance Value Index (IVI) of tree species across agroforestry sites

Scientific name	Local name	Family	RD _i	FR	DR	IVI
Karangrejo Village						
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	<i>Akasia</i>	Fabaceae	9.22	8.93	3.25	21.40
<i>Adonidia merrillii</i> (Becc.) Becc.	<i>Palm</i>	Arecaceae	2.13	3.57	0.75	6.45
<i>Alstonia macrophylla</i> Wall. ex G.Don	<i>Pulai batu</i>	Apocynaceae	1.42	1.79	0.5	3.70
<i>Annona muricata</i> L.	<i>Sirsak</i>	Annonaceae	0.71	1.79	0.25	2.74
<i>Artocarpus heterophyllus</i> Lam.	<i>Nangka</i>	Moraceae	7.80	10.71	2.75	21.27
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	0.71	1.79	0.25	2.74
<i>Cocos nucifera</i> L.	<i>Kelapa</i>	Arecaceae	7.80	10.71	2.75	21.27
<i>Dendrocalamus giganteus</i> Munro	<i>Bambu</i>	Poaceae	15.60	1.79	5.5	22.89
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	11.35	7.14	4	22.49
<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	<i>Sengon</i>	Fabaceae	4.26	3.57	1.5	9.33
<i>Gnetum gnemon</i> L.	<i>Melinjo</i>	Gnetaceae	1.42	1.79	0.5	3.70
<i>Hibiscus tiliaceus</i> L.	<i>Waru</i>	Malvaceae	1.42	3.57	0.5	5.49
<i>Mangifera indica</i> L.	<i>Mangga</i>	Anacardiaceae	3.55	5.36	1.25	10.15
<i>Moringa oleifera</i> Lam.	<i>Kelor</i>	Moringaceae	0.71	1.79	0.25	2.74
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	2.13	1.79	0.75	4.66
<i>Nephelium lappaceum</i> L.	<i>Rambutan</i>	Sapindaceae	2.13	5.36	0.75	8.23
<i>Parkia speciosa</i> Hassk.	<i>Petai</i>	Fabaceae	7.80	7.14	2.75	17.69
<i>Persea americana</i> Mill.	<i>Alpukat</i>	Lauraceae	4.96	7.14	1.75	13.86
<i>Swietenia mahagoni</i> (L.) Jacq.	<i>Mahoni</i>	Meliaceae	4.26	3.57	1.5	9.33
<i>Tectona grandis</i> L.f.	<i>Jati</i>	Lamiaceae	10.64	10.71	3.75	25.10
Ngargoyoso Village						
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	<i>Akasia</i>	Fabaceae	1.09	2.50	0.25	3.84
<i>Archidendron pauciflorum</i> (Benth.) I.C.Nielsen	<i>Jengkol</i>	Fabaceae	3.26	2.50	0.75	6.51
<i>Artocarpus heterophyllus</i> Lam.	<i>Nangka</i>	Moraceae	3.26	7.50	0.75	11.51
<i>Calliandra haematocephala</i> Hassk.	<i>Kaliandra</i>	Fabaceae	2.17	2.50	0.50	5.17
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	2.17	2.50	0.50	5.17
<i>Citrus hystrix</i> DC.	<i>Jeruk</i>	Rutaceae	1.09	2.50	0.25	3.84
<i>Dendrocalamus giganteus</i> Munro	<i>Bambu</i>	Poaceae	32.61	2.50	7.50	42.61
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	17.39	17.50	4.00	38.89
<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	<i>Sengon</i>	Fabaceae	5.43	10.00	1.25	16.68
<i>Ficus carica</i> L.	<i>Buah tin</i>	Moraceae	1.09	2.50	0.25	3.84
<i>Gliricidia sepium</i> (Jacq.) Kunth	<i>Gamal</i>	Fabaceae	1.09	2.50	0.25	3.84
<i>Gnetum gnemon</i> L.	<i>Melinjo</i>	Gnetaceae	4.35	7.50	1.00	12.85
<i>Hibiscus tiliaceus</i> L.	<i>Waru</i>	Malvaceae	1.09	2.50	0.25	3.84
<i>Mangifera indica</i> L.	<i>Mangga apel</i>	Anacardiaceae	6.52	7.50	1.50	15.52
<i>Syzygium aromaticum</i> (L.) Merr. & L.M.Perry	<i>Cengkeh</i>	Myrtaceae	4.35	2.50	1.00	7.85
<i>Nephelium lappaceum</i> L.	<i>Rambutan</i>	Sapindaceae	1.09	2.50	0.25	3.84
<i>Persea americana</i> Mill.	<i>Alpukat</i>	Lauraceae	3.26	7.50	0.75	11.51
<i>Syzygium aqueum</i> (Burm. f.) Alston	<i>Jambu air</i>	Myrtaceae	1.09	2.50	0.25	3.84
<i>Psidium guajava</i> L. cv. "Kristal"	<i>Jambu kristal</i>	Myrtaceae	2.17	2.50	0.50	5.17
<i>Tectona grandis</i> L.f.	<i>Jati</i>	Lamiaceae	5.43	10.00	1.25	16.68
Berjo Village						
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	<i>Akasia</i>	Fabaceae	1.43	3.33	0.43	5.20
<i>Artocarpus heterophyllus</i> Lam.	<i>Nangka</i>	Moraceae	5.71	8.33	1.74	15.79
<i>Azadirachta indica</i> A.Juss.	<i>Mimba</i>	Meliaceae	7.14	6.67	2.17	15.98
<i>Dendrocalamus giganteus</i> Munro	<i>Bambu</i>	Poaceae	22.86	3.33	6.96	33.15
<i>Dimocarpus longan</i> Lour.	<i>Kelengkeng</i>	Sapindaceae	0.71	1.67	0.22	2.60
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	5.71	6.67	1.74	14.12
<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	<i>Sengon</i>	Fabaceae	2.86	5.00	0.87	8.73
<i>Gliricidia sepium</i> (Jacq.) Kunth	<i>Gamal</i>	Fabaceae	0.71	1.67	0.22	2.60
<i>Gnetum gnemon</i> L.	<i>Melinjo</i>	Gnetaceae	2.14	3.33	0.65	6.13
<i>Hibiscus tiliaceus</i> L.	<i>Waru</i>	Malvaceae	4.29	5.00	1.30	10.59
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Lamtoro</i>	Fabaceae	2.14	3.33	0.65	6.13
<i>Mangifera indica</i> L.	<i>Mangga</i>	Anacardiaceae	3.57	5.00	1.09	9.66
<i>Muntingia calabura</i> L.	<i>Talok</i>	Muntingiaceae	0.71	1.67	0.22	2.60
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	2.86	1.67	0.87	5.39
<i>Nephelium lappaceum</i> L.	<i>Rambutan</i>	Sapindaceae	2.14	3.33	0.65	6.13
<i>Persea americana</i> Mill.	<i>Alpukat</i>	Lauraceae	2.86	3.33	0.87	7.06
<i>Pinus merkusii</i> Jungh. & de Vriese	<i>Pinus</i>	Pinaceae	1.43	3.33	0.43	5.20
<i>Platycladus orientalis</i> (L.) Franco	<i>Cemara kipas</i>	Cupressaceae	3.57	6.67	1.09	11.33

<i>Psidium guajava</i> L. cv. "Kristal"	<i>Jambu kristal</i>	Myrtaceae	3.57	3.33	1.09	7.99
<i>Pterocarpus indicus</i> Willd.	<i>Angsana</i>	Fabaceae	3.57	3.33	1.09	7.99
<i>Swietenia mahagoni</i> (L.) Jacq.	<i>Mahoni</i>	Meliaceae	6.43	6.67	1.96	15.05
<i>Syzygium aromaticum</i> (L.) Merr. & L.M.Perry	<i>Cengkeh</i>	Myrtaceae	5.71	3.33	1.74	10.79
<i>Tectona grandis</i> L.f.	<i>Jati</i>	Lamiaceae	7.86	10.00	2.39	20.25

Note: KR: Relative Type Density (%), FR: Relative Frequency (%), DR: Relative Dominance (%), IVI: Important Value Index

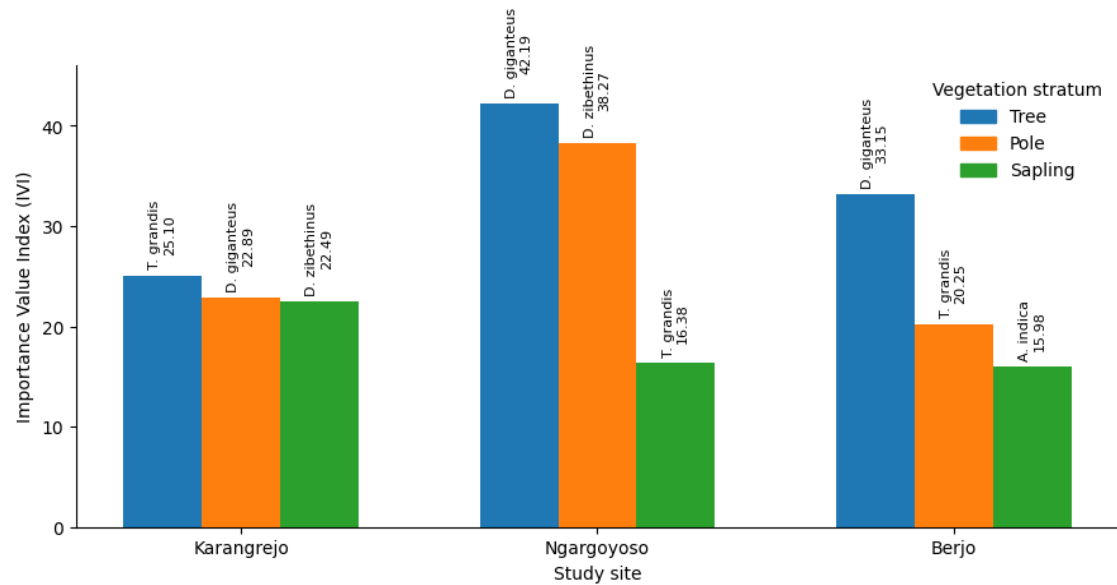


Figure 5. Dominant species based on Importance Value Index (IVI) across sites

Diversity and evenness patterns

Patterns of plant diversity and evenness differed among the three agroforestry sites, as reflected by Shannon-Wiener Diversity (H') and Evenness (E) Indices (Table 6 and Figure 6). Overall, all sites exhibited relatively high diversity values, with H' ranging from 3.38 to 3.76, indicating structurally complex and species-rich plant communities across the Mount Lawu foothills. Evenness values were moderate to high (0.86-0.91), suggesting that individuals were generally well distributed among species despite differences in management intensity and dominance structure.

Among the three villages, Berjo consistently showed the highest diversity and evenness, with H' =3.76 and E =0.91, alongside the highest species richness (66 species). These values indicate not only greater taxonomic diversity but also a more even distribution of individuals among species, suggesting reduced dominance pressure and a relatively balanced contribution of multiple taxa. Such conditions are commonly associated with increased community stability and resilience in managed ecosystems.

Ngargoyoso exhibited intermediate diversity and evenness, with H' =3.43 and E =0.86, despite supporting 52 species. The slightly lower evenness reflects the strong dominance of a few species, particularly at higher

vegetation strata, as indicated by IVI patterns. This indicates that relatively high species richness does not necessarily translate into high evenness when management practices favor specific taxa.

Karangrejo showed the lowest diversity and slightly higher evenness compared to Ngargoyoso, with H' =3.38, E =0.87, and 49 species recorded. This pattern is consistent with its vegetation structure, which emphasizes saplings and younger growth stages with fewer mature trees. Lower diversity in Karangrejo suggests stronger dominance effects and potentially higher species turnover associated with more dynamic or recently modified agroforestry management.

Taken together, the combined interpretation of H' and E reveals a gradient of community stability across sites. High diversity coupled with high evenness, as observed in Berjo, indicates a more stable and balanced agroforestry system. In contrast, sites with lower evenness may be more sensitive to changes affecting dominant species, although relatively high species richness can partially buffer such effects. These findings highlight how local management decisions shape diversity patterns and ecological stability within agroforestry systems along the Mount Lawu foothills.

Table 4. Importance Value Index (IVI) of pole species across agroforestry sites

Scientific name	Local name	Family	RDi	FR	DR	IVI
Karangrejo Village						
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	<i>Akasia</i>	Fabaceae	1.03	3.13	0.53	4.68
<i>Alpinia galanga</i> (L.) Willd.	<i>Lengkuas</i>	Zingiberaceae	20.62	3.13	10.53	34.27
<i>Amorphophallus oncophyllus</i> Prain ex Hook.f.	<i>Porang</i>	Araceae	4.12	3.13	2.11	9.35
<i>Archidendron pauciflorum</i> (Benth.) I.C.Nielsen	<i>Jengkol</i>	Fabaceae	1.03	3.13	0.53	4.68
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	6.19	9.38	3.16	18.72
<i>Cocos nucifera</i> L.	<i>Kelapa</i>	Arecaceae	4.12	3.13	2.11	9.35
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	9.28	9.38	4.74	23.39
<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	<i>Sengon</i>	Fabaceae	1.03	3.13	0.53	4.68
<i>Gnetum gnemon</i> L.	<i>Melinjo</i>	Gnetaceae	1.03	3.13	0.53	4.68
<i>Hibiscus tiliaceus</i> L.	<i>Waru</i>	Malvaceae	1.03	3.13	0.53	4.68
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Petai cina</i>	Fabaceae	1.03	3.13	0.53	4.68
<i>Mangifera indica</i> L.	<i>Mangga</i>	Anacardiaceae	2.06	6.25	1.05	9.36
<i>Manihot esculenta</i> Crantz	<i>Singkong</i>	Euphorbiaceae	1.03	3.13	0.53	4.68
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	29.90	12.50	15.26	57.66
<i>Parkia speciosa</i> Hassk.	<i>Petai</i>	Fabaceae	1.03	3.13	0.53	4.68
<i>Persea americana</i> Mill.	<i>Alpukat</i>	Lauraceae	1.03	3.13	0.53	4.68
<i>Pterocarpus indicus</i> Willd.	<i>Angsana</i>	Fabaceae	1.03	3.13	0.53	4.68
<i>Tectona grandis</i> L.f.	<i>Jati</i>	Lamiaceae	10.31	18.75	5.26	34.32
<i>Theobroma cacao</i> L.	<i>Cokelat</i>	Malvaceae	3.09	3.13	1.58	7.80
Ngargoyoso Village						
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	<i>Akasia</i>	Fabaceae	7.07	7.69	2.92	17.68
<i>Annona muricata</i> L.	<i>Sirsak</i>	Annonaceae	1.01	2.56	0.42	3.99
<i>Calliandra haematocephala</i> Hassk.	<i>Kaliandra</i>	Fabaceae	4.04	2.56	1.67	8.27
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	11.11	10.26	4.58	25.95
<i>Citrus limon</i> (L.) Osbeck	<i>Jeruk Lemon</i>	Rutaceae	2.02	2.56	0.83	5.42
<i>Clitoria ternatea</i> L.	<i>Telang</i>	Fabaceae	1.01	2.56	0.42	3.99
<i>Cocos nucifera</i> L.	<i>Kelapa</i>	Arecaceae	2.02	2.56	0.83	5.42
<i>Cordyline fruticosa</i> (L.) A.Chev.	<i>Andong</i>	Asparagaceae	3.03	2.56	1.25	6.84
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	6.06	7.69	2.50	16.25
<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	<i>Sengon</i>	Fabaceae	1.01	2.56	0.42	3.99
<i>Gliricidia sepium</i> (Jacq.) Kunth	<i>Gamal</i>	Fabaceae	1.01	2.56	0.42	3.99
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Petai China</i>	Fabaceae	3.03	5.13	1.25	9.41
<i>Mangifera indica</i> L.	<i>Mangga</i>	Anacardiaceae	3.03	5.13	1.25	9.41
<i>Manihot esculenta</i> Crantz	<i>Singkong</i>	Euphorbiaceae	17.17	5.13	7.08	29.38
<i>Manilkara zapota</i> (L.) P.Royen	<i>Sawo</i>	Sapotaceae	1.01	2.56	0.42	3.99
<i>Muntingia calabura</i> L.	<i>Talok</i>	Muntingiaceae	1.01	2.56	0.42	3.99
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	14.14	7.69	5.83	27.67
<i>Syzygium aromaticum</i> (L.) Merr. & L.M.Perry	<i>Cengkeh</i>	Myrtaceae	1.01	2.56	0.42	3.99
<i>Persea americana</i> Mill.	<i>Alpukat</i>	Lauraceae	1.01	2.56	0.42	3.99
<i>Platyserium bifurcatum</i> (Cav) C.Chr.	<i>Pakis</i>	Polypodiaceae	1.01	2.56	0.42	3.99
<i>Psidium guajava</i> L. cv. "Kristal"	<i>Jambu Kristal</i>	Myrtaceae	7.07	7.69	2.92	17.68
<i>Streblus asper</i> Lour.	<i>Serut</i>	Moraceae	2.02	2.56	0.83	5.42
<i>Syzygium oleana</i> Walp.	<i>Pucuk Merah</i>	Myrtaceae	2.02	5.13	0.83	7.98
<i>Xanthosoma sagittifolium</i> (L.) Schott	<i>Talas</i>	Araceae	7.07	2.56	2.92	12.55
Berjo Village						
<i>Adonidia merrillii</i> Becc.	<i>Palem putri</i>	Arecaceae	3.80	2.56	1.20	7.56
<i>Angiopteris evecta</i> (G.Forst.) Hoffm	<i>Paku gajah</i>	Marattiaceae	8.86	5.13	2.80	16.79
<i>Artocarpus heterophyllus</i> Lam.	<i>Nangka</i>	Moraceae	1.27	2.56	0.40	4.23
<i>Azadirachta indica</i> A.Juss.	<i>Mimba</i>	Meliaceae	3.80	2.56	1.20	7.56
<i>Bismarckia nobilis</i> Hildebrandt & H.Wendl.	<i>palm</i>	Arecaceae	3.80	2.56	1.20	7.56
<i>Breynia androgyna</i> (L.) Chakrab. & N.P.Balabr.	<i>Katuk</i>	Phyllanthaceae	3.80	5.13	1.20	10.13
<i>Calliandra calothyrsus</i> Meisn.	<i>Kaliandra</i>	Fabaceae	3.80	2.56	1.20	7.56
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	3.80	2.56	1.20	7.56
<i>Cordyline fruticosa</i> (L.) A.Chev.	<i>Andong Merah</i>	Asparagaceae	1.27	2.56	0.40	4.23
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	3.80	2.56	1.20	7.56
<i>Gliricidia sepium</i> (Jacq.) Kunth	<i>Gamal</i>	Fabaceae	1.27	2.56	0.40	4.23
<i>Gnetum gnemon</i> L.	<i>Melinjo</i>	Gnetaceae	1.27	2.56	0.40	4.23
<i>Hibiscus tiliaceus</i> L.	<i>Waru</i>	Malvaceae	3.80	7.69	1.20	12.69
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Petai cina</i>	Fabaceae	11.39	7.69	3.60	22.68
<i>Mangifera indica</i> L.	<i>Mangga</i>	Anacardiaceae	1.27	2.56	0.40	4.23

<i>Manihot carthagenensis</i> subsp. <i>glaziovii</i> (Müll.Arg.) Allem	<i>Singkong karet</i>	Euphorbiaceae	2.53	2.56	0.80	5.90
<i>Manihot esculenta</i> Crantz	<i>singkong</i>	Euphorbiaceae	6.33	2.56	2.00	10.89
<i>Muntingia calabura</i> L.	<i>Talok</i>	Muntingiaceae	3.80	5.13	1.20	10.13
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	8.86	5.13	2.80	16.79
<i>Nyctanthes arbor-tristis</i> L.	<i>Sri gading putih</i>	Oleaceae	1.27	2.56	0.40	4.23
<i>Persea americana</i> Mill.	<i>Alpukat</i>	Lauraceae	3.80	7.69	1.20	12.69
<i>Psidium guajava</i> L.	<i>Jambu</i>	Myrtaceae	3.80	5.13	1.20	10.13
<i>Syzygium aromaticum</i> (L.) Merr. & L.M.Perry	<i>Cengkeh</i>	Myrtaceae	5.06	5.13	1.60	11.79
<i>Tectona grandis</i> L.f.	<i>Jati</i>	Lamiaceae	5.06	5.13	1.60	11.79
<i>Ziziphus mauritiana</i> Lam.	<i>Bidara</i>	Rhamnaceae	2.53	5.13	0.80	8.46

Note: KR: Relative Species (%), FR: Relative Frequency (%); RD: Relative Dominance (%), IVI: Important Value Index

Discussion

Structural complexity of agroforestry systems

The agroforestry systems along the Mount Lawu foothills exhibit pronounced structural complexity, as reflected by their multi-layered vegetation organization comprising tree, pole, and sapling strata. Such a stratified structure is a defining characteristic of well-managed tropical agroforestry systems and plays a central role in supporting ecological functions while sustaining agricultural production. The presence of multiple vegetation strata across all study sites indicates that agroforestry in this landscape functions as more than a simplified production system, instead resembling a semi-natural forest structure shaped by deliberate human management.

Vertical stratification enhances ecological complexity by increasing niche availability, light-use efficiency, and spatial heterogeneity within plant communities. Tree strata provide canopy cover that moderates microclimatic conditions, reduces temperature extremes, and buffers soil moisture fluctuations (Isoralla et al. 2025), while intermediate pole strata contribute to structural continuity and future canopy recruitment. Sapling layers, in turn, represent active regeneration and long-term system persistence. The coexistence of these strata across sites indicates that agroforestry systems along the Mount Lawu foothills maintain structural attributes commonly associated with resilient tropical forest ecosystems.

Differences in vertical structure among sites reflect contrasting management strategies and stand development stages. Sites with relatively balanced distributions of individuals across tree, pole, and sapling strata indicate stable agroforestry configurations in which harvesting, planting, and natural regeneration are well integrated. In contrast, sites dominated by saplings and intermediate-sized individuals suggest more dynamic systems characterized by active establishment, recent modification, or higher turnover rates. Such variability highlights that structural complexity in agroforestry is not static but responds to local management objectives, species selection, and land-use history.

Structural complexity is closely linked to the provision of ecosystem services in agroforestry landscapes. Multi-layered vegetation enhances carbon sequestration through increased biomass storage across strata, improves soil

fertility via litter input and root interactions, and reduces erosion by maintaining continuous ground and canopy cover. Additionally, structurally complex systems support greater biodiversity by providing diverse habitats for understory plants, epiphytes, invertebrates, birds, and other fauna. These ecological benefits have been widely documented in tropical agroforestry systems and are considered fundamental to their sustainability (Bhagwat et al. 2008; Jose 2009; van Noordwijk et al. 2014).

The interaction between vegetation structure and species dominance further shapes agroforestry complexity. Dominant canopy-forming species with high importance values contribute disproportionately to vertical structure, microclimate regulation, and habitat formation, while subordinate species enrich compositional diversity and functional redundancy. The integration of IVI-based dominance patterns with vertical structural attributes illustrates how management-driven species selection interacts with ecological processes to produce multifunctional agroforestry systems that balance productivity with environmental stability (Tables 2-5).

Importantly, even sites exhibiting less balanced structural profiles retained multiple vegetation strata, underscoring the inherent flexibility of agroforestry systems in accommodating both production and ecological functions. This flexibility allows farmers to adjust species composition and stand structure in response to socio-economic needs without fundamentally compromising ecological complexity. Such adaptive capacity is a key advantage of agroforestry compared to monoculture-based land-use systems and contributes to its resilience under changing environmental and economic conditions (Nair and Garrity 2012; Mbow et al. 2014).

The stratified vegetation structure documented in this study indicates that agroforestry systems along the Mount Lawu foothills possess substantial ecological complexity. This complexity underpins the delivery of multiple ecosystem services and provides a foundation for long-term sustainability. By integrating vertical structural characteristics with species dominance patterns, the findings highlight how agroforestry management can reconcile agricultural production with biodiversity conservation in tropical upland regions, reinforcing the role of structurally complex agroforestry as a viable and sustainable land-use strategy.

Table 5. Importance Value Index (IVI) of sapling species across agroforestry sites

Scientific name	Local name	Family	RDi	FR	DR	IVI
Karangrejo Village						
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	<i>Akasia</i>	Fabaceae	0.97	3.03	2.58	6.58
<i>Acalypha siamensis</i> Oliv. ex Gage	<i>Teh-tehan</i>	Euphorbiaceae	3.40	3.03	9.03	15.46
<i>Alpinia galanga</i> (L.) Willd.	<i>Lengkuas</i>	Zingiberaceae	6.31	3.03	16.77	26.12
<i>Amaranthus hybridus</i> L.	<i>Bayam</i>	Amaranthaceae	2.18	1.52	5.81	9.51
<i>Amorpha fruticosa</i> L.	<i>Semak Indigo</i>	Fabaceae	0.73	1.52	1.94	4.18
<i>Amorphophallus oncophyllus</i> Prain ex Hook.f.	<i>Porang</i>	Araceae	1.46	1.52	3.87	6.84
<i>Amorphophallus paeoniifolius</i> (Dennst.) Nicolson	<i>Suweg</i>	Araceae	1.21	1.52	3.23	5.95
<i>Annona muricata</i> L.	<i>Sirsak</i>	Annonaceae	0.49	1.52	1.29	3.29
<i>Artocarpus heterophyllus</i> Lam.	<i>Nangka</i>	Moraceae	0.24	1.52	0.65	2.40
<i>Axonopus compressus</i> (Sw.) P.Beauv	<i>Rumput gajah</i>	Poaceae	2.18	1.52	5.81	9.51
<i>Capsicum frutescens</i> L.	<i>Cabai</i>	Solanaceae	4.13	3.03	10.97	18.12
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	0.24	1.52	0.65	2.40
<i>Citrus hystrix</i> DC.	<i>Jeruk purut</i>	Rutaceae	1.46	3.03	3.87	8.36
<i>Cordyline fruticosa</i> (L.) A.Chev.	<i>Andong</i>	Asparagaceae	5.10	4.55	13.55	23.19
<i>Cosmos caudatus</i> Kunth	<i>Kenikir</i>	Asteraceae	1.46	1.52	3.87	6.84
<i>Curcuma heyneana</i> Valeton & Zijp	<i>Temu giring</i>	Zingiberaceae	5.58	3.03	14.84	23.45
<i>Curcuma longa</i> L.	<i>Kunyit</i>	Zingiberaceae	15.53	12.12	41.29	68.95
<i>Cymbopogon nardus</i> (L.) Rendle	<i>Serai</i>	Poaceae	0.97	1.52	2.58	5.07
<i>Dieffenbachia humilis</i> Poepp.	<i>Diven</i>	Araceae	0.49	1.52	1.29	3.29
<i>Dieffenbachia seguine</i> (Jacq.) Schott	<i>Sri rejeki</i>	Araceae	1.46	1.52	3.87	6.84
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	3.16	4.55	8.39	16.09
<i>Ficus carica</i> L.	<i>Buah Tin</i>	Moraceae	0.24	1.52	0.65	2.40
<i>Gnetum gnemon</i> L.	<i>Melinjo</i>	Gnetaceae	0.49	1.52	1.29	3.29
<i>Hibiscus tiliaceus</i> L.	<i>Waru</i>	Malvaceae	0.73	3.03	1.94	5.69
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Petai cina</i>	Fabaceae	0.24	1.52	0.65	2.40
<i>Mangifera indica</i> L.	<i>Mangga</i>	Anacardiaceae	0.24	1.52	0.65	2.40
<i>Manihot carthagenensis</i> subsp. <i>glaziovii</i> (Müll.Arg.)	<i>Singkong karet</i>	Euphorbiaceae	2.67	1.52	7.10	11.28
Allem						
<i>Manihot esculenta</i> Crantz	<i>Singkong</i>	Euphorbiaceae	13.35	10.61	35.48	59.44
<i>Morinda citrifolia</i> L.	<i>Mangkudu</i>	Rubiaceae	0.24	1.52	0.65	2.40
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	1.70	1.52	4.52	7.73
<i>Polyalthia longifolia</i> (Sonn.) Benth. & Hook.f. ex	<i>Banitan</i>	Annonaceae	3.40	1.52	9.03	13.95
Thwaites.						
<i>Solanum melongena</i> L.	<i>Terong</i>	Solanaceae	1.21	1.52	3.23	5.95
<i>Solanum torvum</i> Sw.	<i>Terung</i>	Solanaceae	0.24	1.52	0.65	2.40
	<i>pipit/Cepokak</i>					
<i>Theobroma cacao</i> L.	<i>Cokelat</i>	Malvaceae	0.49	1.52	1.29	3.29
<i>Xanthosoma sagittifolium</i> (L.) Schott	<i>Talas</i>	Araceae	13.35	10.61	35.48	59.44
<i>Zingiber officinale</i> Roscoe	<i>Jahe</i>	Zingiberaceae	2.67	1.52	7.10	11.28
Ngargoyoso Village						
<i>Allium cepa</i> var. <i>aggregatum</i> G.Don	<i>Bawang merah</i>	Amaryllidaceae	1.68	1.49	6.15	9.33
<i>Alpinia galanga</i> (L.) Willd.	<i>Lengkuas</i>	Zingiberaceae	4.20	4.48	15.38	24.06
<i>Amorphophallus Muelleri</i> Blume	<i>Porang</i>	Araceae	1.26	1.49	4.62	7.37
<i>Ananas comosus</i> L. Merr	<i>Nanas</i>	Bromeliaceae	0.21	1.49	0.77	2.47
<i>Angiopteris evecta</i> (G.Forst.) Hoffm	<i>Paku gajah</i>	Marattiaceae	2.10	1.49	7.69	11.29
<i>Axonopus compressus</i> (Sw.) P.Beauv	<i>Rumput gajah</i>	Poaceae	10.92	7.46	40.00	58.39
<i>Capsicum frutescens</i> L.	<i>Cabai rawit</i>	Solanaceae	4.62	4.48	16.92	26.02
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	0.21	1.49	0.77	2.47
<i>Cocos nucifera</i> L.	<i>Kelapa</i>	Arecaceae	0.42	2.99	1.54	4.94
<i>Colocasia esculenta</i> (L.) Schott	<i>Talas loma</i>	Araceae	8.19	5.97	30.00	44.16
<i>Cordyline fruticosa</i> (L.) A.Chev.	<i>Andong</i>	Asparagaceae	6.51	7.46	23.85	37.82
<i>Cosmos caudatus</i> Kunth	<i>Kenikir</i>	Asteraceae	4.41	4.48	16.15	25.04
<i>Curcuma longa</i> L.	<i>Kunyit</i>	Zingiberaceae	9.03	8.96	33.08	51.07
<i>Cymbopogon nardus</i> (L.) Rendle	<i>Sereh</i>	Poaceae	12.39	8.96	45.38	66.73
<i>Hylocereus undatus</i> (Haw.) Britton & Rose	<i>Buah naga</i>	Cactaceae	1.05	1.49	3.85	6.39
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Petai china</i>	Fabaceae	1.68	2.99	6.15	10.82
<i>Manihot carthagenensis</i> subsp. <i>glaziovii</i> (Müll.Arg.)	<i>Singkong Karet</i>	Euphorbiaceae	1.89	2.99	6.92	11.80
Allem						
<i>Manihot esculenta</i> Crantz	<i>Singkong</i>	Euphorbiaceae	8.19	8.96	30.00	47.15
<i>Muntingia calabura</i> L.	<i>Talok</i>	Muntingiaceae	0.84	1.49	3.08	5.41
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	3.15	4.48	11.54	19.17

<i>Piper nigrum</i> L.	<i>Merica</i>	Piperaceae	1.05	2.99	3.85	7.88
<i>Sechium edule</i> (Jacq.) Chayote	<i>Labu siam</i>	Cucurbitaceae	3.15	1.49	11.54	16.18
<i>Solanum melongena</i> L.	<i>Terong</i>	Solanaceae	3.15	2.99	11.54	17.67
<i>Vigna unguiculata</i> (L.) Walp	<i>Kacang panjang</i>	Fabaceae	3.36	1.49	12.31	17.16
<i>Xanthosoma sagittifolium</i> (L.) Schott	<i>Talas</i>	Araceae	3.36	1.49	12.31	17.16
<i>Zingiber officinale</i> Roscoe	<i>Jahe</i>	Zingiberaceae	2.94	4.48	10.77	18.19
Berjo Village						
<i>Adiantum macrophyllum</i> Sw.	<i>Suplir</i>	Pteridaceae	1.06	1.54	1.95	4.55
<i>Allium cepa</i> var. <i>aggregatum</i> G.Don	<i>Bawang Merah</i>	Amaryllidaceae	3.43	1.54	6.34	11.31
<i>Alpinia galanga</i> (L.) Willd.	<i>Lengkuas</i>	Zingiberaceae	0.79	1.54	1.46	3.79
<i>Amaranthus hybridus</i> L.	<i>Bayam</i>	Amaranthaceae	3.17	1.54	5.85	10.56
<i>Ananas comosus</i> (L.) Merr	<i>Nanas</i>	Bromeliaceae	0.79	1.54	1.46	3.79
Angiopteris <i>evecta</i> (G.Forst.) Hoffm	<i>Paku gajah</i>	Marattiaceae	5.01	6.15	9.27	20.44
<i>Arrhenatherum elatius</i> (L.) P.Beauv. ex J.Presl & C.Presl	<i>Oat Grass</i>	Poaceae	3.43	1.54	6.34	11.31
<i>Axonopus compressus</i> (Sw.) P.Beauv	<i>Rumput Gajah</i>	Poaceae	13.72	7.69	25.37	46.78
<i>Begonia abbottii</i> Urb	<i>Begonia</i>	Begoniaceae	0.26	1.54	0.49	2.29
<i>Bougainvillea glabra</i> Choisy	<i>Bougenville</i>	Nyctaginaceae	0.79	1.54	1.46	3.79
<i>Calliandra haematocephala</i> Hassk.	<i>Kaliandra</i>	Fabaceae	1.85	1.54	3.41	6.80
<i>Capsicum frutescens</i> L.	<i>Cabai Rawit</i>	Solanaceae	6.33	3.08	11.71	21.12
<i>Carica papaya</i> L.	<i>Pepaya</i>	Caricaceae	1.06	3.08	1.95	6.08
<i>Citrus limon</i> (L.) Osbeck	<i>Jeruk Lemon</i>	Rutaceae	0.79	1.54	1.46	3.79
<i>Coleus abyssinicus</i> (Fresen.) A.J.Paton	<i>Coleus</i>	Lamiaceae	1.06	1.54	1.95	4.55
<i>Colocasia esculenta</i> (L.) Schott	<i>Talas Loma</i>	Araceae	0.79	1.54	1.46	3.79
<i>Cordyline fruticosa</i> (L.) A.Chev.	<i>Andong</i>	Asparagaceae	4.22	6.15	7.80	18.18
<i>Cosmos caudatus</i> Kunth	<i>Kenikir</i>	Asteraceae	3.43	3.08	6.34	12.85
<i>Cucurbita moschata</i> Duchesne	<i>Labu Kuning</i>	Cucurbitaceae	0.79	1.54	1.46	3.79
<i>Curcuma longa</i> L.	<i>Kunyit</i>	Zingiberaceae	1.85	1.54	3.41	6.80
<i>Cymbopogon nardus</i> (L.) Rendle	<i>Sereh</i>	Poaceae	1.06	1.54	1.95	4.55
<i>Durio zibethinus</i> L.	<i>Durian</i>	Malvaceae	0.53	1.54	0.98	3.04
<i>Gardenia jasminoides</i> J.Ellis	<i>Cape Jasmine</i>	Rubiaceae	0.53	1.54	0.98	3.04
<i>Hibiscus rosa-sinensis</i> L.	<i>Bunga Sepatu</i>	Malvaceae	0.26	1.54	0.49	2.29
<i>Impatiens walleriana</i> Hook.f.	<i>Impatiens</i>	Balsaminaceae	1.06	1.54	1.95	4.55
<i>Lantana camara</i> L.	<i>Bunga Tahi Ayam</i>	Verbenaceae	2.11	3.08	3.90	9.09
<i>Leucaena leucocephala</i> (Lam.) de Wit	<i>Petai Cina</i>	Fabaceae	1.06	3.08	1.95	6.08
<i>Manihot esculenta</i> Crantz	<i>Singkong</i>	Euphorbiaceae	9.76	4.62	18.05	32.43
<i>Musa acuminata</i> Colla	<i>Pisang</i>	Musaceae	2.90	3.08	5.37	11.35
<i>Nepeta cataria</i> L.	<i>Catnip</i>	Lamiaceae	1.32	1.54	2.44	5.30
<i>Orthosiphon stamineus</i> (Blume)Miq	<i>Teh-Tehan</i>	Lamiaceae	1.32	1.54	2.44	5.30
<i>Phaseolus vulgaris</i> L.	<i>Buncis</i>	Fabaceae	3.17	1.54	5.85	10.56
<i>Psidium guajava</i> L. cv. "Kristal"	<i>Jambu Kristal</i>	Myrtaceae	0.26	1.54	0.49	2.29
<i>Salacca zalacca</i> (Gaertn.) Voss	<i>Salak</i>	Arecaceae	1.58	1.54	2.93	6.05
<i>Solanum melongena</i> L.	<i>Terong</i>	Solanaceae	0.79	1.54	1.46	3.79
<i>Solanum torvum</i> Sw.	<i>Terung</i>	Solanaceae	0.26	1.54	0.49	2.29
<i>Taraxacum officinale</i> (L.) Weber ex F.H.Wigg.	<i>Pipit/Cepokak</i>					
<i>Theobroma cacao</i> L.	<i>Dandelion</i>	Asteraceae	2.37	3.08	4.39	9.84
<i>Vigna unguiculata</i> (L.) Walp	<i>Cokelat</i>	Malvaceae	0.26	1.54	0.49	2.29
<i>Wedelia trilobata</i> (L.) Pruski	<i>Kacang Panjang</i>	Fabaceae	3.69	1.54	6.83	12.06
<i>Xanthosoma sagittifolium</i> (L.) Schott	<i>Wedelia</i>	Asteraceae	4.22	4.62	7.80	16.64
	<i>Talas</i>	Araceae	6.86	6.15	12.68	25.70

Note: KR: Relative Species (%), FR: Relative Frequency (%); RD: Relative Dominance (%), IVI: Important Value Index

Species dominance and management preferences

Species dominance patterns in agroforestry systems along the Mount Lawu foothills strongly reflect human management preferences, particularly the prioritization of economically valuable and multifunctional species. Importance Value Index (IVI) analysis showed that dominance was consistently concentrated in a limited number of taxa across sites, notably teak (*T. grandis*), bamboo (*D. giganteus*), and durian (*D. zibethinus*), which exerted a disproportionate influence on stand structure and resource allocation (Figure 5 and Table 7). This pattern underscores the role of deliberate species selection and

retention in shaping vegetation composition within smallholder agroforestry systems.

Teak emerged as a dominant or co-dominant canopy species in Karangrejo and Berjo, with IVI values reaching 25.10 and 20.25, respectively. Its dominance reflects a long-standing preference for teak as a high-value timber species in Java, driven by favorable growth characteristics, durability, and strong market demand. The presence of teak across growth stages indicates sustained recruitment and intentional maintenance, consistent with patterns reported from other Javanese agroforestry landscapes (Pandey and Brown 2000; Nair and Garrity 2012). Ecologically, teak

contributes to canopy formation and microclimate regulation, although its dominance may reduce light availability for understory species and thereby influence community composition.

Bamboo (*D. giganteus*) exhibited particularly strong dominance in Ngargoyoso and Berjo, where IVI values reached 42.19 and 33.15, respectively. Such high dominance highlights bamboo's multifunctional role as a rapidly growing structural species valued for construction material, erosion control, and slope stabilization. Its presence across growth strata suggests active promotion and long-term retention within agroforestry systems.

Comparable dominance of bamboo has been widely documented in agroforestry and mixed garden systems across Asia, where clump-forming bamboo species are deliberately maintained due to their capacity for repeated harvesting while simultaneously providing important ecological functions, particularly soil stabilization, slope reinforcement, and erosion control in sloping agricultural landscapes (Ben-zhi et al. 2005; Nair et al. 2009; Nair and Garrity 2012).

Durian (*D. zibethinus*) represents a contrasting dominance pattern driven primarily by fruit production rather than timber or structural roles. High IVI values across all sites, reaching 38.27 in Ngargoyoso and remaining above 22 in Karangrejo, indicate that fruit trees form integral components of canopy structure in Mount Lawu agroforestry systems. This dominance reflects market-oriented management strategies that prioritize high-value seasonal crops, while continued presence across strata indicates ongoing planting and regeneration. Similar patterns have been documented in fruit-based agroforestry systems in Indonesia and Malaysia (Kumar and Nair 2004; Schroth et al. 2004; Hariyadi et al. 2025). Beyond economic benefits, durian contributes to canopy heterogeneity and provides food resources for wildlife.

The dominance of these economically important species illustrates the extent to which human intervention shapes agroforestry structure. Selective planting, thinning, and harvesting reinforce the dominance of preferred taxa while constraining the expansion of less valued species. As a result, community composition differs markedly from unmanaged forest systems, where competitive interactions and environmental filtering more strongly govern dominance patterns (Chazdon 2014; Poorter et al. 2016). In agroforestry contexts, dominance therefore emerges as a hybrid outcome of ecological processes and socio-economic objectives.

Despite strong dominance by a few key species, agroforestry systems along the Mount Lawu foothills retain a diverse assemblage of subordinate taxa with lower IVI values. These species contribute to structural heterogeneity and functional diversity by providing ground cover, soil improvement, fodder, medicinal resources, and supplementary food sources. The coexistence of dominant economic species with a functionally diverse pool of secondary taxa is a defining characteristic of traditional agroforestry systems and has been widely reported across

tropical regions (Perfecto and Vandermeer 2010; Tschardt et al. 2011).

The dominance of teak, bamboo, and durian in Mount Lawu agroforestry systems indicates how management preferences shape vegetation structure to balance economic returns with ecological functions. Although dominance by a few species can reduce evenness, the persistence of multiple vegetation strata and the presence of functionally important subordinate species indicate that these systems maintain considerable ecological complexity. Understanding the interaction between species dominance and management preferences is therefore critical for designing agroforestry strategies that sustain productivity while conserving biodiversity and ecosystem services in tropical upland landscapes.

Diversity patterns and ecological stability

Patterns of Shannon-Wiener Diversity (H') and Evenness (E) across the Mount Lawu foothills provide important insights into the ecological stability of agroforestry systems (Table 6 and Figure 6). Across sites, diversity values were consistently high, with H' ranging from 3.38 to 3.76, while evenness values were moderate to high (0.86-0.91). Such combinations indicate structurally complex plant assemblages in which no single species overwhelmingly dominates community structure. In ecological terms, relatively high diversity coupled with moderate to high evenness is commonly associated with greater system resilience and functional redundancy in managed ecosystems (Magurran 2013).

Table 6. Species richness, Shannon-Wiener Diversity (H'), and Evenness (E) across agroforestry sites

Site	Species richness	Shannon-Wiener Diversity (H')	Evenness (E)
Karangrejo	49	3.38	0.87
Ngargoyoso	52	3.43	0.86
Berjo	66	3.76	0.91

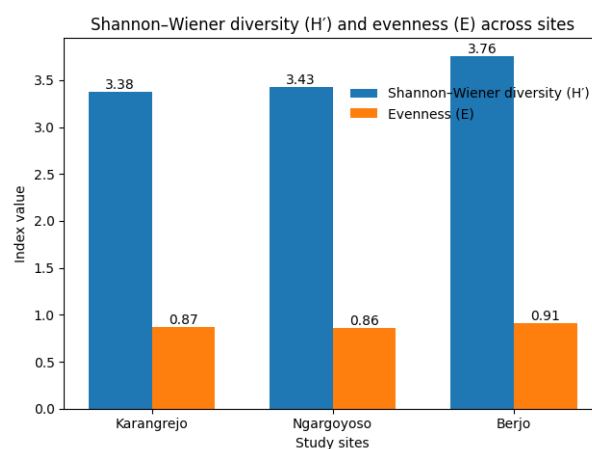


Figure 6. Shannon-Wiener Diversity (H') and Evenness (E) across sites

Table 7. Dominant plant species and their functional roles in agroforestry systems along the Mount Lawu foothills, Central Java, Indonesia

Species	Vegetation stratum	Dominant site(s)	Ecological role	Socio-economic role	Reference
<i>Tectona grandis</i>	Tree	Karangrejo, Berjo	Canopy former, microclimate regulation, soil improvement	High-value timber, long-term income source	Baghel and Raut (2023)
<i>Dendrocalamus giganteus</i>	Tree	Ngargoyoso, Berjo	Carbon sequestration, erosion control, habitat structure	Construction material, crafts, and cultural use	Sudchaleaw et al. (2023), Rani et al. (2024)
<i>Durio zibethinus</i>	Tree	All sites	Food resource, canopy diversity	Fruit production, household, and market income	Thorogood et al. (2022), Akdah et al. (2024)
<i>Musa acuminata</i>	Pole	Karangrejo, Ngargoyoso	Mid-story vegetation, nutrient cycling	Staple fruit crop, short-term income	Marod et al. (2010), Reza et al. (2025)
<i>Manihot esculenta</i>	Pole, Sapling	Ngargoyoso, Berjo	Ground cover, soil stabilization	Carbohydrate source, food security	Irawan et al. (2024), Mutanda et al. (2025)
<i>Leucaena leucocephala</i>	Pole	Berjo	Nitrogen fixation, soil fertility improvement	Fodder, fuelwood	Neupane (2025), Saensouk et al. (2025)
<i>Curcuma longa</i>	Sapling	Karangrejo	Understory diversity, soil health support	Medicinal plant, spice commodity	Soliman et al. (2023), Niamngon et al. (2023), Safitri et al. (2025)
<i>Cymbopogon nardus</i>	Sapling	Ngargoyoso	Soil cover, pest deterrence	Essential oil source, medicinal use	Telaumbanua et al. (2021), Yudiyanto et al. (2022), Rahmayani et al. (2024)
<i>Axonopus compressus</i>	Sapling	Berjo	Erosion control, ground cover	Low-maintenance forage, land stabilization	Samedani et al. (2013), Tay et al. (2020)
<i>Alpinia galanga</i>	Sapling	Karangrejo, Ngargoyoso	Understory complexity, nutrient cycling	Culinary spice, traditional medicine	Evbuomwan et al. (2023), Rahmayani et al. (2024), Ma et al. (2026)

Site-level variation in H' and E reflects differences in dominance intensity and management history. Berjo, which recorded the highest diversity ($H'=3.76$) and evenness ($E=0.91$) alongside the greatest species richness (66 species), represents a community structure characterized by balanced species contributions and reduced dominance pressure. High evenness suggests more equitable resource partitioning among species, a condition that can buffer agroforestry systems against environmental perturbations and selective harvesting. Communities with such attributes tend to exhibit greater resistance to species loss and more stable ecosystem functioning over time (Loreau and de Mazancourt 2013; Tilman et al. 2014).

In contrast, Ngargoyoso and Karangrejo exhibited slightly lower evenness values ($E=0.86$ and 0.87 , respectively), despite maintaining relatively high diversity ($H'=3.43$ and 3.38). This pattern reflects stronger dominance by a subset of economically favored species, as indicated by IVI results. Ecologically, reduced evenness implies increased dependence on dominant taxa, potentially increasing vulnerability to disturbances that disproportionately affect those species, such as pest outbreaks or market-driven overharvesting. However, the

persistence of relatively high species richness (52 species in Ngargoyoso and 49 species in Karangrejo) suggests that a diverse pool of subordinate species remains available to support functional diversity and ecological buffering.

Comparisons with other agroforestry systems in Java indicate that diversity levels observed in the Mount Lawu foothills are comparable to, or exceed, those reported from traditional mixed garden (*kebun campuran*) systems in West and Central Java. Previous studies have documented moderate to high H' values in agroforestry landscapes where timber and fruit trees are intercropped with understory crops, particularly under long-term management regimes (Sardjono et al. 2003; Kehlenbeck et al. 2007; Hairiah et al. 2011). These similarities suggest that the Mount Lawu systems conform to a broader regional pattern of structurally and compositionally diverse agroforestry landscapes.

At the Southeast Asian scale, agroforestry systems typically exhibit diversity patterns intermediate between natural forests and monoculture plantations. Studies from Indonesia, Malaysia, and the Philippines demonstrate that complex agroforestry systems can maintain high plant diversity and moderate evenness while remaining

economically productive (Kumar and Nair 2004; Schroth et al. 2004; Clough et al. 2011; Saraan et al. 2025). The diversity patterns documented in the Mount Lawu foothills align with these regional trends, reinforcing the role of agroforestry as a biodiversity-friendly production system in tropical landscapes.

Ecological stability in agroforestry systems emerges from the interaction between diversity and dominance. While strong dominance by economically important species can reduce evenness, it does not necessarily undermine system stability if sufficient species richness and vertical structural complexity are maintained. In the present study, sites with lower evenness still retained multiple vegetation strata and diverse species pools, indicating a form of managed stability in which human intervention shapes community structure without eliminating ecological buffering capacity. This condition has been described as “managed resilience,” whereby stability arises from deliberate balancing of production goals and ecological processes (Perfecto and Vandermeer 2010; Altieri et al. 2015).

Overall, variation in H' and E among sites reflects differing management strategies and dominance intensities, yet consistently high diversity values indicate that agroforestry systems along the Mount Lawu foothills maintain substantial ecological stability. When viewed in the context of agroforestry systems elsewhere in Java and Southeast Asia, these findings support the role of structurally complex and species-rich agroforestry as a resilient land-use option capable of reconciling agricultural production with long-term ecological sustainability.

Implications for sustainable agroforestry management

The structural complexity and species dominance patterns observed in agroforestry systems along the Mount Lawu foothills have important implications for sustainable management strategies that seek to balance biodiversity conservation with agricultural production. The functional roles of dominant and subordinate species demonstrate that these agroforestry systems operate as multifunctional land-use units rather than purely production-oriented systems (Table 7). Recognizing this multifunctionality is essential for designing management practices and policy frameworks that support both ecological integrity and rural livelihoods.

From a conservation perspective, the maintenance of structurally important species across multiple growth strata enhances habitat heterogeneity and ecological buffering. Dominant canopy-forming species contribute to microclimate regulation, soil protection, and structural stability, while a diverse assemblage of subordinate species increases understory complexity and functional redundancy. Management approaches that retain a mixture of timber, fruit, and understory species can therefore support on-farm biodiversity while reducing pressure on adjacent natural forests. Similar outcomes have been documented in agroforestry systems across Java and other parts of Southeast Asia, where mixed-species management has been shown to enhance landscape connectivity and conservation value (Bhagwat et al. 2008; Harvey et al. 2008).

In terms of production, dominance by economically valuable species reflects rational household strategies to secure both short- and long-term income. Long-rotation timber species function as capital investments, fast-growing species provide frequent harvests and structural benefits, and fruit trees generate high seasonal returns. Sustainable agroforestry management should therefore not aim to eliminate species dominance, but rather to regulate its intensity and spatial configuration to avoid excessive structural simplification. Practices such as selective thinning, enrichment planting of underrepresented functional groups, and staggered harvesting schedules can help maintain productivity while preserving vertical and functional balance (Kumar and Nair 2004; Schroth et al. 2004).

Functional considerations are particularly critical in sloping upland environments such as the Mount Lawu foothills. Species with strong soil-binding capacity and extensive root systems play a key role in erosion control and slope stabilization, directly influencing long-term land productivity. Maintaining these species within agroforestry plots represents an ecosystem-based management strategy that simultaneously addresses production needs and environmental constraints. Such approaches are consistent with broader principles of sustainable land management promoted for tropical upland regions (Montagnini and Nair 2004; Palm et al. 2010).

At the policy level, the findings of this study underscore the need better to integrate agroforestry into formal land-use planning in Central Java. Despite their demonstrated ecological and socio-economic benefits, agroforestry systems are often underrepresented in land-use classifications and development programs. Recognizing agroforestry as a distinct and multifunctional land-use category could enable more supportive policies, including technical assistance, incentives for species diversification, and inclusion in watershed management and landscape-scale conservation initiatives (Nair and Garrity 2012; Zomer et al. 2014). In the context of Indonesia's commitments to biodiversity conservation and climate change mitigation, structurally complex agroforestry systems can contribute to both goals through the maintenance of plant diversity and the enhancement of carbon storage.

Local governance structures and agricultural extension services also play a crucial role in shaping agroforestry outcomes. Management recommendations based on species functional traits, rather than uniform planting schemes, are more likely to sustain agroforestry multifunctionality under diverse socio-economic conditions. Extension programs that promote adaptive, site-specific management strategies can strengthen farmers' capacity to balance production objectives with ecological considerations. This approach aligns with participatory and adaptive management frameworks increasingly advocated in rural development and conservation practice (Perfecto and Vandermeer 2010; Altieri et al. 2015).

The implications of this study indicate that sustainable agroforestry management in the Mount Lawu foothills depends on maintaining structural complexity, regulating

species dominance, and explicitly recognizing the multifunctional roles of plant species. Integrating ecological insights with local management practices and supportive policy frameworks can enable agroforestry systems to remain resilient land-use options that sustain livelihoods, conserve biodiversity, and deliver essential ecosystem services in tropical upland landscapes.

The limitations of this study include its spatially restricted sampling area, the absence of temporal (seasonal or interannual) comparisons, and the lack of quantitative socio-economic data linking species dominance directly to farmer decision-making. In addition, the analysis focused on structural and compositional attributes without assessing ecosystem functions such as carbon storage or soil quality. Future studies should incorporate multi-season sampling, expand coverage to other agroforestry landscapes in Java, and integrate socio-economic surveys to explain management drivers better. Further research linking vegetation structure to ecosystem services, such as biomass, carbon sequestration, and soil fertility, would strengthen the role of agroforestry as a science-based strategy for sustainable land management.

In conclusion, agroforestry systems along the Mount Lawu foothills, Central Java, exhibit high plant diversity and pronounced structural complexity, as reflected by the presence of well-developed tree, pole, and sapling strata across all sites. A total of 95 plant species were recorded, with site-level richness ranging from 49 to 66 species, indicating substantial floristic diversity within smallholder-managed systems. Diversity and evenness values were consistently high, with Shannon-Wiener Diversity (H') ranging from 3.38 to 3.76 and evenness (E) from 0.86 to 0.91, suggesting relatively balanced community structures despite active management. Importance Value Index analysis showed that a limited number of economically important species, particularly teak (*T. grandis*), bamboo (*D. giganteus*), and durian (*D. zibethinus*), dominated stand structure, with IVI values reaching up to 42.19. However, the persistence of numerous subordinate species across multiple strata indicates ongoing regeneration and functional diversity. Variation in structural profiles and dominance patterns among sites reflects a continuum of management strategies rather than a uniform land-use type. The preservation of multi-strata structure and species diversity supports key ecosystem functions, including microclimate regulation, soil stabilization, and sustained productivity, underscoring agroforestry as a resilient land-use system capable of integrating livelihood needs with biodiversity conservation in tropical upland landscapes. The high diversity observed in sapling and pole strata further suggests favorable conditions for long-term system stability and regeneration.

ACKNOWLEDGEMENTS

The authors would like to thank the local communities and landowners in Karangrejo, Ngargoyoso, and Berjo Villages, Karanganyar, Central Java, Indonesia, for

granting access to agroforestry fields and for their cooperation during fieldwork.

REFERENCES

- Akdah RD, Wijayanto N, Hartoyo APP. 2024. Species composition, stand structure, and carbon stock in the agroforestry system of Wana Lestari Community Forestry, West Nusa Tenggara, Indonesia. *Biodiversitas* 25: 3350-3358. <https://doi.org/10.13057/biodiv/d250957>.
- Aldrian E, Susanto RD. 2003. Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. *Intl J Climatol* 23: 1435-1452. <https://doi.org/10.1002/joc.950>.
- Altieri MA, Nicholls CI, Henao A, Lana MA. 2015. Agroecology and the design of climate change-resilient farming systems. *Agron Sustain Dev* 35: 869-890. <https://doi.org/10.1007/s13593-015-0285-2>.
- Baghel Y, Raut PD. 2023. Environmental and economic role: A case of *Tectona grandis* study. *Indian J Ecol* 50 (5): 1338-1342. <https://doi.org/10.55362/IJE/2023/4057>.
- Ben-zhi Z, Mao-yi F, Jin-zhong X, Xiao-sheng Y, Zheng-cai L. 2005. Ecological functions of bamboo forest: Research and application. *J For Res* 16: 143-147. <https://doi.org/10.1007/bf02857909>.
- Bhagwat SA, Willis KJ, Birks HJ, Whittaker RJ. 2008. Agroforestry: A refuge for tropical biodiversity? *Trends Ecol Evol* 23 (5): 261-267. <https://doi.org/10.1016/j.tree.2008.01.005>.
- Chazdon RL. 2014. *Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation*. University of Chicago Press, Chicago. <https://doi.org/10.7208/chicago/9780226118109.001.0001>.
- Clough Y, Barkmann J, Jührbandt J, Kessler M, Wanger TC, Anshary A, Buchori D, Cicuzza D, Darras K, Putra DD, Erasmis S, Pitopang R, Schmidt C, Schulze CH, Seidel D, Steffan-Dewenter I, Stenchly K, Vidal S, Weist M, Wielgoss AC, Tschardtke T. 2011. Combining high biodiversity with high yields in tropical agroforests. *Proc Natl Acad Sci USA* 108 (20): 8311-8316. <https://doi.org/10.1073/pnas.1016799108>.
- Curtis JT, McIntosh RP. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* 31: 476-496. <https://doi.org/10.2307/1931725>.
- Evbomwan IO, Stephen Adeyemi O, Oluba OM. 2023. Indigenous medicinal plants used in folk medicine for malaria treatment in Kwara State, Nigeria: an ethnobotanical study. *BMC Complement Med Ther* 23 (1): 324. <https://doi.org/10.1186/s12906-023-04131-4>.
- Hairiah K, Dewi S, Agus F, Velarde SJ, Ekadinata A, Rahayu S, van Noordwijk M. 2011. *Measuring Carbon Stocks Across Land Use Systems: A Manual*. World Agroforestry Centre (ICRAF), Bogor.
- Hariyadi B, Ihsan M, Husnudin UB, Sazali A. 2025. Sustainability of Durian Agroforestry in the Selat Area, Jambi: Population Structure and Management Challenges in a Changing Landscape. *Jurnal Pembelajaran dan Biologi Nukleus* 11 (3): 1137-1159.
- Harvey CA, Komar O, Chazdon R, Ferguson BG, Finegan B, Griffith DM, Martínez-Ramos M, Morales H, Nigh R, Soto-Pinto L, Van Breugel M, Wishnie M. 2008. Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican Hotspot. *Conserv Biol* 22 (1): 8-15. <https://doi.org/10.1111/j.1523-1739.2007.00863.x>.
- Irawan B, Safira KM, Annisa, Rohmatullaly EN, Ihsan M, Suryana, Iskandar J, Iskandar BS. 2024. Ethnobotany of cassava (*Manihot esculenta*) in the traditional peri-urban Sundanese community of Cireundeu Hamlet, Cimahi City, West Java, Indonesia. *Biodiversitas* 25: 116-128. <https://doi.org/10.13057/biodiv/d250113>.
- Isoralla, Djohan TS, Dzaky HL. 2025. The Contribution of Tree Canopies to Microclimate in Urban and Karst Ecosystems in the Special Region of Yogyakarta. *Jurnal Pijar MIPA* 20 (8): 1591-1598. <https://doi.org/10.29303/jpm.v20i8.10816>.
- Jose S. 2009. Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforest Syst* 76 (1): 1-10. <https://doi.org/10.1007/s10457-009-9229-7>.
- Kehlenbeck K, Arifin HS, Maass BL. 2007. Plant diversity in homegardens in a socio-economic and agro-ecological context. In: Tschardtke T, Leuschner C, Zeller M, Guhardja E, Bidin A (eds.). *Stability of Tropical Rainforest Margins*. Springer, Berlin. https://doi.org/10.1007/978-3-540-30290-2_15.
- Kent M. 2012. *Vegetation Description and Data Analysis: A Practical Approach*. 2nd Edition. Wiley-Blackwell, Chichester.

- Kumar BM, Nair PKR. 2004. The enigma of tropical homegardens. *Agrofor Syst* 61: 135-152. <https://doi.org/10.1023/b:agfo.0000028995.13227.ca>.
- Loreau M, de Mazancourt C. 2013. Biodiversity and ecosystem stability: A synthesis of underlying mechanisms. *Ecol Lett* 16: 106-115. <https://doi.org/10.1111/ele.12073>.
- Ma D, Liu J, Zi Y, Yang R, Huang S, Yao X, Yang M. 2026. Canopy density modulates plant-soil interactions and nutrient status in a *Dalbergia odorifera*–*Alpinia galanga* agroforestry system. *Agroforest Syst* 100: 76. <https://doi.org/10.1007/s10457-026-01458-y>.
- Magurran AE. 2013. *Measuring Biological Diversity*. Wiley-Blackwell, Oxford.
- Marod D, Pinyo P, Duengkak P, Hiroshi T. 2010. The role of wild banana (*Musa acuminata* Colla) on wildlife diversity in mixed deciduous forest, Kanchanaburi Province, Western Thailand. *Kasetsart J Nat Sci* 44: 35-43.
- Mbow C, van Noordwijk M, Luedeling E, Neufeldt H, Minang PA, Kowero G. 2014. Agroforestry solutions to address food security and climate change challenges in Africa. *Curr Opin Environ Sustain* 6: 61-67. <https://doi.org/10.1016/j.cosust.2013.10.014>.
- Montagnini F, Nair PKR. 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agrofor Syst* 61: 281-295. <https://doi.org/10.1023/b:agfo.0000029005.92691.79>.
- Mueller-Dombois D, Ellenberg H. 1974. *Aims and Methods of Vegetation Ecology*. Wiley, New York.
- Mutanda M, Amelewok AB, Ndou N, Figlan S. 2025. Drought Stress in Cassava (*Manihot esculenta*): Management Strategies and Breeding Technologies. *Intl J Plant Biol* 16 (4): 112. <https://doi.org/10.3390/ijpb16040112>.
- Nair PKR, Garrity D (eds.). 2012. *Agroforestry – The Future of Global Land Use*. Springer, Dordrecht. <https://doi.org/10.1007/978-94-007-4676-3>.
- Nair PKR, Kumar BM, Nair VD. 2009. Agroforestry as a strategy for carbon sequestration. *J Plant Nutr Soil Sci* 172: 10-23. <https://doi.org/10.1002/jpln.200800030>.
- Nair PKR. 1993. *An Introduction to Agroforestry*. Kluwer Academic Publishers, Dordrecht.
- Neupane D. 2025. Ipil-Ipil (*Leucaena Leucocephala*): A Multipurpose Leguminous Tree For Agrobiodiversity Conservation And Climate - Resilient Farming. *Trop Agroecosyst* 8 (2): 77-80. <http://doi.org/10.26480/taec.02.2025.77.80>
- Niamngon P, Saensouk S, Saensouk P, Junsongduang A. 2023. Ethnobotanical knowledge of Isaan Laos tribe in Khong Chai District, Kalasin Province, Thailand with particular focus on medicinal uses. *Biodiversitas* 24: 6793-6824. <https://doi.org/10.13057/biodiv/d241242>.
- Palm CA, Smukler SM, Sullivan CC, Mutuo PK, Nyadzzi GI, Walsh MG. 2010. Identifying potential synergies and trade-offs for meeting food security and climate change objectives in Sub-Saharan Africa. *Proc Natl Acad Sci USA* 107 (46): 19661-19666. <https://doi.org/10.1073/pnas.0912248107>.
- Pandey D, Brown C. 2000. Teak: A global overview. *Unasyuva* 51: 3–13. <https://www.fao.org>.
- Perfecto I, Vandermeer J. 2010. The agroecological matrix as an alternative to the land-sparing/agriculture intensification model. *Proc Natl Acad Sci USA* 107 (13): 5786-5791. <https://doi.org/10.1073/pnas.0905455107>.
- Philip MS. 1994. *Measuring Trees and Forests*. 2nd Edition. CAB International, Wallingford. <https://doi.org/10.1079/9780851988832.0000>.
- Pielou EC. 1966. The measurement of diversity in different types of biological collections. *J Theor Biol* 13: 131-144. [https://doi.org/10.1016/0022-5193\(66\)90013-0](https://doi.org/10.1016/0022-5193(66)90013-0).
- Poorter L, Bongers F, Aide TM et al. 2016. Biomass resilience of Neotropical secondary forests. *Nature* 530: 211-214. <https://doi.org/10.1038/nature16512>.
- Rahmayani D, Fatikha LA, Azizia MS, Tsabita FA, Cahyaningsih AP, Setyawan AD. 2023. The use of plants on rural homegarden agroforestry system by village communities in Karanganyar District, Central Java, Indonesia. *Pros Sem Nas Masy Biodiv Indon* 9: 91-105.
- Rani M, Lathwal M, Vikas, Indira A, Joshi B, Kalyan N, Chongtham N. 2024. Role of bamboo in environmental conservation and sustainable development. 12th World Bamboo Congress. Taiwan 18-22 April 2024.
- Reza AD, Firdausi E, Kusuma LA, Sabrina MA, Fadhillah EN, Md Naim D, Setyawan AD. 2025. Traditional knowledge and utilization of non-medicinal plants in homegardens of a tropical karst landscape in Central Java, Indonesia. *Intl J Trop Drylands* 9: 20-35. <https://doi.org/10.13057/tropdrylands/t090103>.
- Saensouk P, Saensouk S, Boonma T, Rakarcha S, Setyawan AD, Chanthavongsa K, Jitpromma T. 2025. Ethnobotanical heritage of Ban Nongtae Community Forest, Ban Dan District, Buri Ram Province, Thailand. *Asian J Ethnobiol* 8: 182-191. <https://doi.org/10.13057/asianjethnobiol/y080205>.
- Safitri RN, Hanum U, Pratiwi VMR, Hermawan WG, Nurcahyati M, Budiharta S, Setyawan AD. 2025. Ethnobotanical knowledge of edible plants in a karst landscape of Gawang Hamlet, Ketro Village, Pacitan District, Indonesia. *Intl J Trop Drylands* 9: 85-97. <https://doi.org/10.13057/tropdrylands/t090108>.
- Samedani B, Juraimi AS, Anwar MP, Rafii MY, Sheikh Awadz SH, Anuar AR. 2013. Competitive interaction of *Axonopus compressus* and *Asystasia gangetica* under contrasting sunlight intensity. *Scientific World J* 2013: 308646. <https://doi.org/10.1155/2013/308646>.
- Saraan M, Rahmawaty, Harahap RH, Hilmi E, Delvian, Sibarani R. 2025. Agroforestry-based plant diversity and its implications for ecosystem restoration in Gunung Leuser National Park, Indonesia. *Biodiversitas* 26: 6367-6377. <https://doi.org/10.13057/biodiv/d261234>.
- Sardjono MA, Djogo T, Arifin HS, Wijayanto N. 2003. Classification and Function of Agroforestry Systems in Indonesia. World Agroforestry Centre (ICRAF), Bogor.
- Schroth G, da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN. 2004. *Agroforestry and Biodiversity Conservation in Tropical Landscapes*. Island Press, Washington DC.
- Shannon CE, Weaver W. 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.
- Soliman YM, Soliman WS, Abbas AM. 2023. Alley Cropping and Organic Compost: An Efficient and Sustainable Agro-Ecological Strategy for Improving Turmeric (*Curcuma longa* L.) Growth and Attributes. *Agriculture* 13 (1): 149. <https://doi.org/10.3390/agriculture13010149>.
- Sudchaleaw S, Saensouk S, Saensouk P, Sungkaew S. 2023. Species diversity and traditional utilization of bamboos (Poaceae) on the Phu Thai Ethnic Group in northeastern Thailand. *Biodiversitas* 24: 2261-2271. <https://doi.org/10.13057/biodiv/d240439>.
- Tay AC, Ratnam P. 2020. IOP Conf Ser: Mater Sci Eng 943: 012025. <https://doi.org/10.1088/1757-899X/943/1/012025>.
- Telaumbanua M, Savitri EA, Shofi AB, Suharyatun S, Wisnu FK, Haryanto A. 2021. IOP Conf Ser: Earth Environ Sci 739: 012071. <https://doi.org/10.1088/1755-1315/739/1/012071>.
- Thorogood CJ, Ghazalli MN, Siti-Munirah MY, Nikong D, Kusuma YWC, Sudarmono S, Witono JR. 2022. The king of fruits. *Plants, People, Planet* 4 (6): 538-547. <https://doi.org/10.1002/ppp3.10288>.
- Tilman D, Isbell F, Cowles JM. 2014. Biodiversity and ecosystem functioning. *Ann Rev Ecol Evol Syst* 45: 471-493. <https://doi.org/10.1146/annurev-ecolsys-120213-091917>.
- Tschamtké T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, Vandermeer J, Whitbread A. 2012. Global food security, biodiversity conservation, and the future of agricultural intensification. *Biol Conserv* 151 (1): 53-59. <https://doi.org/10.1016/j.biocon.2012.01.068>.
- Udawatta RP, Rankoth L, Jose S. 2019. Agroforestry and Biodiversity. *Sustainability* 11 (10): 2879. <https://doi.org/10.3390/su11102879>.
- van Noordwijk M, Duguma LA, Dewi S, Leimona B, Catacutan D, Lusiana B, Öborn I, Hairiah K, Minang PA. 2014. Agroforestry is a multifunctional land use. In: van Noordwijk M, Leimona B, Lasco RD et al. (eds). *Climate Change Mitigation and Adaptation in Agriculture*. Springer, Dordrecht.
- Whitten T, Soeriaatmadja RE, Afiff SA. 1996. *The Ecology of Java and Bali*. Oxford University Press, Oxford.
- Yudiyanto, Hakim N, Wakhidah AZ. 2022. Ethnobotany of medicinal plants from Lampung Tribe around Way Kambas National Park, Indonesia. *Nusantara Biosci* 14: 84-94. <https://doi.org/10.13057/nusbiosci/n140111>.
- Zomer RJ, Trabucco A, Coe R, Place F, van Noordwijk M, Xu J. 2014. *Trees on Farms: An Update and Reanalysis of Agroforestry's Global Extent and Socio-ecological Characteristics*. Working Paper 179. World Agroforestry Centre (ICRAF), Bogor. <https://doi.org/10.5716/wp14064.pdf>.