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Comparison of Woody Plant Species Diversity in Agroforestry Systems: Insights from Isingiro District, Uganda

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Abstract: Agroforestry systems contribute to biodiversity and ecological resilience across tropical savanna landscapes, yet their comparative influence on woody plant community dynamics remains understudied. This research examines spatial patterns of woody species abundance, richness, and diversity across silvoarable, silvopastoral, and agrosilvopastoral systems in the Isingiro District of Uganda, applying plot-based sampling across 30 farms. Species richness was highest in silvopastoral systems, whereas silvoarable systems supported greater diversity and evenness. Although Analysis of Variance (ANOVA) revealed statistically non-significant differences for abundance and diversity, species composition trends suggest functional distinctions among systems. The dominance of Fabaceae, particularly *Euphorbia tirucalli*, across systems points to shared ecological traits and land-use preferences. These findings highlight agroforestry's role in maintaining woody plant heterogeneity within East African savanna mosaics and highlight its relevance to nature-based climate adaptation strategies. Through aligning biodiversity outcomes with landscape configuration, this study contributes to agroecosystem planning and conservation frameworks relevant to the region's Nationally Determined Contributions (NDC) commitments and resilience agendas.

Keywords: Savannas; Agroforestry; Diversity; Conservation.

INTRODUCTION

Woody plant species have been highly degraded within semi-arid areas of Africa due to high demand for arable land and unsustainable cropping systems. The Agroforestry (AF) system is one of the approaches to saving many woody species from extinction. Furthermore, the system is one of the nature-based solutions to reversing and reducing land degradation and concomitant benefits of food security and biodiversity conservation. Agroforestry practices are molded by planting, retention, or managed regrowth of woody plant species on farms. Trees in agroforestry systems are environmentally beneficial because they support soil ecosystems and sustain livelihoods. The loss of tree varieties would result in significant negative changes to ecosystems, ranging from the destruction of microniches to global warming (González-Valdivia *et al.*, 2017).

Human beings can influence the diversity of woody plant species within various landscapes across the world, due to their preferences in different regions, for different utilization purposes (Tabuti *et al.,* 2022). This influence can bring about an increase in specific species within a region and a decrease in others. The decrease may be due to over utilization and harvesting, especially species utilized for timber production and firewood. Nevertheless, Basamba *et al.* (2016) highlights that agroforestry has greatly expanded within the Eastern Africa region, especially within forest scarce countries. Basamba *et al.* (2016) study further indicates that this has been evidenced through the farms of Kenya and Ethiopia accounting for higher quantities of poles and timber produced in the countries.

Climate change is being addressed through the Paris Agreement by keeping global temperature rise well below 2ºC above pre-industrial levels this century, and by striving to limit the temperatures to 1.5ºC. Several African countries have pledged to contribute to this goal through their Nationally Determined Contributions (NDCs) by utilizing Nature-based Solutions (NbS) such as forestry and agroforestry. However, there have been no clear lines of action on achieving this in a sustainable manner. Many African countries such as Eritrea, Ethiopia, and Uganda have proposed forestry projects that aim to increase the amount of monoculture plantations of exotic fast-growing woody species (Seddon *et al.,* 2020). Instead, this could devolve into an unsustainable method of reaching the Paris Agreement goal. Agroforestry systems that are well designed to consider the optimal selection of woody plant species, particularly native species, can go a long way towards attaining some of these goals. Therefore, proper designing of agroforestry practices as a nature-based solution capable of effectively delivering sustainable development especially in savanna areas is important.

Previous studies (Aryal *et al.* 2019; Tadesse *et al*. 2019) have assessed woody plant species diversity in savanna areas. However, there remains a gap in assessment of woody plant species diversity across the different agroforestry systems to understand the suitability of the different woody plant species under various AF systems within fragile ecosystems such as savannas. A study by Aryal *et al.* (2019) investigates tree diversity and composition in pasturelands using a combination of remote sensing and in situ measurements in Mexico. Whereas the study provides comprehensive results on tree diversity in pasturelands, it did not specifically address woody plant species diversity across different agroforestry systems, which calls for comparative assessment of diversity across different agroforestry systems such as silvopastoral, silvoarable, and agrosilvopastoral, using various methods such as remote sensing and field-based methods.

A study by Tadesse *et al.* (2019) examined woody plant species diversity in traditional agroforestry practices, such as home gardens and scattered trees on farmlands in Assosa District in western Ethiopia. Tadesse *et al.* (2019) study employed field surveys and plot sampling to collect data, which was then analyzed using diversity indices; Shannon-Wiener and Simpson's. Whereas Tadesse *et al.* (2019) study focused on diversity within agroforestry systems, it did not compare diversity across different types of agroforestry practices in the region. Therefore, the present study addresses this clear need for research that specifically compares woody plant species diversity across different types of agroforestry systems within East African savannas, specifically, southwestern Uganda. In particular, the study compares the species abundance, richness and diversity across silvoarable, silvopastoral and agrosilvopastoral systems in Isingiro District.

Agroforestry systems in tropical savannas not only stabilize woody plant populations but also function as keystone structures for landscape-level ecological connectivity and biodiversity corridors (Burel & Baudry, 2005; Pardon *et al*., 2017). Through integrating trees into agricultural matrices, these systems mitigate fragmentation and enhance functional continuity across heterogenous land-use mosaics. According to Aryal *et al. (*2019), silvopastoralism, a system that integrates woody plant species and grasses for purposes of fodder for animal grazing, shade, soil nutrient recycling, mitigating climate change among other benefits is a common agroforestry system in savannas. Silvopastoral systems encompass different layouts, among which include spatially distributed trees on pasturelands, woody plantations with pastures, feed banks, live fences, and pastures with dense fodder trees. The silvoarable agroforestry system, which combines tree cultivation with crop production on the same land, has garnered significant attention in sustainable agriculture in various agroecological areas.

The silvoarable agroforestry system aims to optimize land use and increase biodiversity while ensuring economic viability. A study by Lawson *et al.* (2019) has shown that silvoarable systems can enhance soil quality, improve water retention, and increase carbon sequestration, contributing to environmental sustainability. Agrosilvopastoral systems, which integrate crop cultivation, woody plants, and livestock rearing, are increasingly recognized for their multifunctional benefits in sustainable agriculture. This AF approach can lead to enhanced biodiversity, improved soil health, and increased economic resilience for farmers. Livestock components in these systems contribute to nutrient cycling and soil fertility, as highlighted by Aryal *et al*., (2019). Moreover, the strategic use of tree cover can provide shelter for crops and animals, enhancing productivity. Challenges with this system include managing the complex interactions between system components and ensuring sustainable stocking rates. Our research question was, how different agroforestry systems silvoarable, silvopastoral, and agrosilvopastoral influence woody species abundance, richness, and diversity across savanna landscapes in Isingiro District, Uganda

Theoretical framework

The study is supported by the theory of Biodiversity and Ecosystems Functioning (BEF) relationships in AF systems (Schwarz *et al.,* 2021). This theory is based on principles that emphasize the ecological functioning of AF system components while recognizing the relevance of socio-cultural and economic criteria in designing successful AF systems. Plant diversity positively impacts the ecosystem functioning and other natural resources such as forests. Therefore, production system optimization provides a variety of ecosystem services.

AF is encouraged for sustainable intensification of agriculture and for restoring degraded landscapes. Schwarz *et al.* (2021) further elaborates that at present, the ability to develop causal links between diversity and the functioning of AF systems is bounded because of the numerous non-controlled effects, such as tree density, management intensity and technical capacities, which may be distracted by diversity effects. Additionally, even within a single geographical region, there are significant differences in AF systems, especially based on integrated cultivated crop

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species. As a result, determining the type of AF practice most promising requires AF systems research.

Based on this theory, when species are chosen at random or based on traits, it fuels the reduction in species abundance from species communities to monocultures, which results in loss of biodiversity in such scenarios. On the contrary, diversity in AF systems is not always assembled at random but rather based on the suitability of species to support socioeconomic adaptability and solve major environmental problem for example soil erosion. As a result, approaches in which species are chosen based on specific functional traits appear to be more appropriate for designing AF systems.

Conceptual Framework

Figure 1 presents the conceptual framework guiding the study, illustrating the interrelationships between different agroforestry practices and their impacts on biodiversity and ecosystem services. This model is essential for understanding how various AF systems contribute to the ecological and economic outcomes.

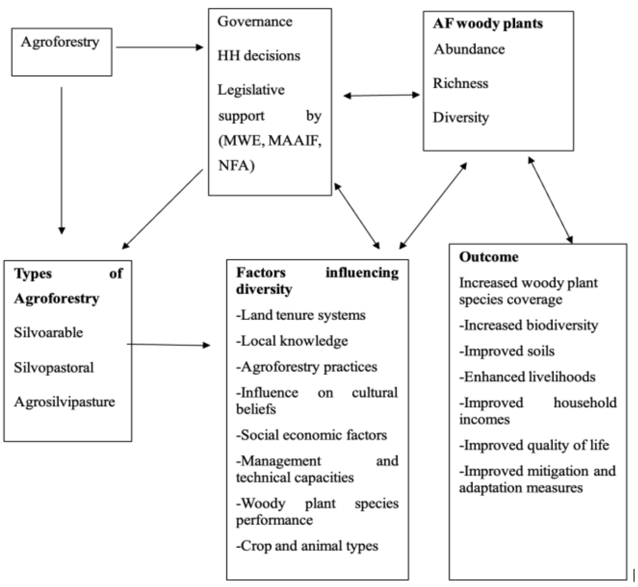

Figure 1 Conceptual framework

Agroforestry systems play a crucial role in enhancing biodiversity, improving soil health, and supporting livelihoods especially in fragile ecosystems such as savannas. However, the effectiveness of these systems is usually hampered by several gaps, especially inadequate technical support, financial incentives to farmers, research-based policy reforms from relevant governance authorities etc.

Additionally, various factors affect diversity of woody plant species in AF systems. Among these include the management and technical capacities of the farmers, unsustainable agricultural practices that do not consider agroforestry systems, and monocultural practices, over exploitation through charcoal burning among others. Research on the diversity of woody plant species within different AF systems can support the policy makers to amend existing policies and programs especially under agricultural and environmental institutions. This would result in improved woody species diversity and coverage within the AF systems that exist within the area/region. This thereby improves biodiversity, soils, incomes and quality of life while contributing to climate adaptation and mitigation.

MATERIALS AND METHODS

This study followed a descriptive research design to obtain quantitative data. The target population in this study was farmers who practice agroforestry, in Kyarugaju parish - Kabingo subcounty in Isingiro district, Uganda. Within the parish, three villages of Kagamba, Kyarugaju and Kakyombeka were randomly sampled out of the 8 total villages in the parish (Figure 2). Both primary and secondary data were collected. Initially a reconnaissance field visit was conducted in August 2023 to test the feasibility of the study objectives.

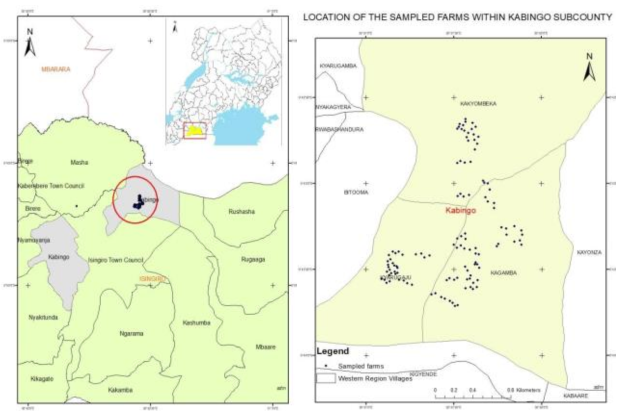

Figure 2. Map of Kabingo subcounty in Isingiro district showing the sampled area. Source: UBO181\l 1033 (UBOS, Uganda administrative boundaries, 2018)

Sample size determination

A woody plant assessment was conducted across 30 farms, purposively selected to represent three distinct agroforestry systems. Ten (10) farms of each system silvoarable, silvopastoral, and agrosilvipasture were evaluated to ensure balanced representation and enable comparative analysis of species diversity, structural composition, and system-specific management practices.

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Data collection methods

Both primary and secondary data and information were collected to address the study objectives. Primary data was collected through on-farm walks with heads of households to obtain data on the woody plant species diversity. This study considered woody plants as trees and shrubs, where trees are plants that grow from a single main stem/trunk, and a shrub refers to self-supporting multistemmed woody plants. The sampling methodology adopted in this study mirrors the approach utilized by Molla and Kewessa (2015). A standard 1-hectare plot was established for each of the 30 total assessed farms. All woody plants (trees and shrubs) encountered in the sampled areas of agroforestry systems; silvopastoral, silvoarable and agrosilvipasture were recorded. Within each 1-hectare plot of each farm, 4 alternating subplots of size 20m × 20 m (400 m^2) were laid along line transects each separated by 15m. Trees and shrubs that were encountered during assessment were recorded in local names and later, recorded in their scientific names. Observation of tree and shrub species was done in identification, and the PlantNet Application was used for identification of some of the woody plants that couldn't be identified easily. During identification, species images that exhibited a high plant net score of above 85% (family and genus) and species-level identification of about 70% within the application findings, were the most likely species (Hart *et al*., 2023). These were further identified using the taxonomy identification book (Katende *et al*., 1995). For samples of those woody plants that could not be identified immediately in the field, sample collection and preservation in newspaper sheets was done and an expert opinion was sought.

Data analysis

Woody plant species indices

Data collected under the different categories of agroforestry systems was managed and quantified in Microsoft Excel data sheet. Species richness, abundance and diversity were calculated for the different Agroforestry systems. Species diversity was analyzed using Shannon Wiener and Simpson's indices. Species diversity is composed of species richness and evenness (the relative abundance of each species), and it was derived from the Shannon Weiner diversity index (Shumi *et al*., 2021). Plot level accumulation curves were used to illustrate the cumulative species richness within each agroforestry system. Simpson's alpha and beta diversities were calculated to make differences in diversity within and between systems respectively (Shumi *et al*., 2021). The Shannon index is shown in Equation 1:

Equation 1

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

- H′ represents the Shannon Diversity index;
- P_i represents the importance value of a species as a proportion of all species (that is the proportion (n/N) of individuals of one species found (n) divided by the total number of individuals found (N),
- ln represents the natural log,
- Σ represents the summation of the calculations,
- s represents species number

According to Sagar and Sharma (2012), Simpson's index equation is shown in Equation 2:

Equation 2

$$\text{Simpson Index (D)} = \frac{1}{\sum_{i=1}^{s} p_i^2} \text{ where;}$$

- p represents proportion (n/N)
- (n), individuals of one particular species
- N, the total sum of individuals found, and
- Σ represents the summation of s number of species

To carry out statistical tests, the collected data was first checked for normality using Kolmogorov Smirnov test and equality of variance using Levene's test following (Manaye *et al*., 2021). The variation in woody plant species richness, abundance, and diversity was described by mean and standard deviation. One-way ANOVA was performed to test differences in woody plant species diversity, abundance, and richness between pairs of systems for the three agroforestry systems, and statistical tests were performed at 5% level of significance. A Tukey multiple pairwise comparison test was made to test for significance of differences among the AF systems following results from the ANOVA. The data was managed with R software (version 4.3.2), using vegan, car and ggplot2 packages, and Microsoft Excel 2016.

RESULTS AND DISCUSSION

Results

Floristic composition

Altogether, 58 woody plant species belonging to 26 families were recorded in the three assessed categories of agroforestry. Among the woody plants, trees constituted 60%, shrubs 12%, whereas 28% can be categorized as tree or shrub based on the size and forking height (Götmark *et al.,* 2016). Among the 26 families found in the studied agroforestry systems, Fabaceae was the most dominant represented by 11 species. This result is consistent with findings by Molla *et al*. (2023) who reported Fabaceae as the dominant family in their research on diversity of woody plants in traditional agroforestry systems of south-central Ethiopia. The most likely reason for this might be that the households' preference is inclined towards growing leguminous crops and medicinal plants in their farmland.

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Woody plant species abundance under different AF systems

The highest number of total woody plants count was recorded under the silvopastoral system, 468 (i.e. 293 woody plants/ha), followed by the Agrosilvopastoral system that was composed of 317 total woody plants (i.e. 198 woody plants/ha). The least number of woody plants count was recorded under the silvoarable system which was 227 (i.e. 142 woody plants/ha). The silvopastoral system revealed the highest mean woody plant species abundance (8.07 ± 2.96), followed by the agrosilvopastoral system (5.47 ± 1.69). Silvoarable system exhibited the least mean woody plant abundance (3.91 ± 0.96) compared to silvopastoral and agrosilvopastoral systems. The species abundance was not significantly different (p > 0.05) across the three systems (Table 1).

Table 1 provides statistical summaries of woody plant species abundance across different agroforestry systems assessed in the study. The variations in abundance across systems highlight the ecological impacts of agroforestry configurations.

Table 1: Woody plant species abundance under different AF systems

AF System	Minimum	Mean ± SE Mean	StDev	Variance	Maximum
Silvoarable	0.00	3.91 ± 0.96	7.31	53.41	30.00
Silvopastoral	0.00	8.07 ± 2.96	22.5	509.36	157.00
Agrosilvopastoral	0.00	5.47 ± 1.69	12.86	165.41	82.00
		F-value = 1.0534 P-value =0.3510			

NB: ***The 95% confidence intervals (CIs) represent the average within which the true mean species abundance is likely to fall. They provide a measure of uncertainty and reliability for the overserved values across the different agroforestry systems.***

Woody plant species richness under different AF systems

The silvopastoral AF system exhibited the highest species richness of 44 species, followed by the silvoarable system with a species richness of 28. The agrosilvopastoral system exhibited the lowest species richness of 27. The species richness significantly differed among the three assessed agroforestry systems (p<0.05) as indicated in Table 2. The species richness of woody plants also significantly differed between silvopastoral and agrosilvopastoral, and between silvopastoral and silvoarable, but there was no significant difference between the species richness of silvoarable and agrosilvopastoral agroforestry systems (Table 4). Species richness gradually increased across the three systems as the number of individuals and sampling intensity increased (Figure 3).

Table 2 lists the richness of woody plant species found under each agroforestry system in Kabingo subcounty. This data is crucial for assessing the biodiversity contributions of different systems.

Table 2. Woody plant species richness under different AF systems in Kabingo subcounty, Isingiro District

AF System	Species Richness	Rank
Silvoarable	28	2
Agrosilvipasture	27	3
Silvopastoral	44	1

Table 3 presents the results from the one-way ANOVA testing differences in woody plant abundance, richness, and diversity across agroforestry systems. The results show that species richness differs significantly among the agroforestry systems (P< 0.01). This P value indicates a statistically significant difference with a very low probability that the observed variation occurred by chance, indicating that at least one agroforestry system supports a distinctly higher or lower number of woody plant species. The results justify further pairwise comparisons to identify which systems differ and reasons why. This is further explored in Table 4, which compares significant differences in species diversity indicators.

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Table 3. One-way ANOVA: Comparative analysis of woody plant abundance, richness and diversity across different agroforestry systems

Diversity indicators	F-value	p-value
Species abundance	1.0534	0.3510
Shannon-Wiener	0.1645	0.8484
Species richness	9.1972	0.0001

NB: *The 95% confidence intervals (C**Is**) based on the pooled standard deviation indicate the range within which the true mean of each diversity indicator is expected to fall. The intervals support assessment of whether the observed differences among agroforestry systems are statistically meaningful and not due to random variation.*

Figure 3 shows the species richness observed in different agroforestry systems. It provides a comparative view of diversity levels across systems, highlighting variations and trends that are key to analysis of agroforestry's impact on local biodiversity.

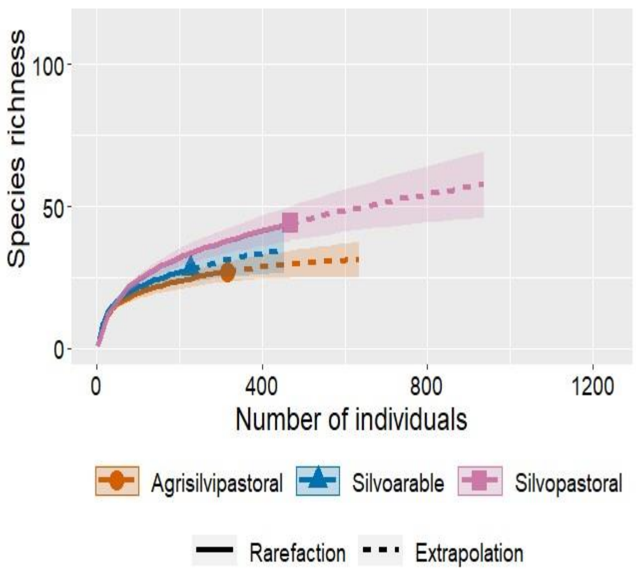

Figure 3 Species richness within different agroforestry systems

Table 4 provides the results from Tukey's multiple comparison test, which evaluates the differences in woody plant species abundance, richness, and diversity among the agroforestry systems studied. This table is instrumental in identifying statistically significant differences between the systems, helping to show the specific impacts of each agroforestry practice on woody plant species metrics. The analysis focuses on comparing each pair of systems to understand where significant variations in biodiversity indices exist, which is crucial for targeted agroforestry management and conservation efforts.

The Tukey multiple pairwise comparison test indicated that the estimate of -1.5517 implies that silvoarable system has a lower mean abundance than agrosilvipasture system, but with an adjusted p-value (P=0.8535), this difference is not statistically significant. The positive estimate of 2.6034 shows that the silvopastoral system has a higher mean abundance than the agrosilvopastoral system, but with an adjusted p-value (P=0.6411), this difference is not statistically significant. The estimate of 4.1552 indicates the silvopastoral system has a higher mean abundance than the silvoarable, but the adjusted p-value (P=0.3246) indicates that this difference is not statistically significant (Table 4). Among the species, *Euphorbia tirucalli* generally exhibited a higher abundance across the systems followed by *Combretum molle*, *Carica papaya* and *Eucalyptus grandis* Appendix I and II.

Table 4 Turkey multiple comparison test: Comparative analysis of woody plant species abundance, richness and diversity between AF systems

Agroforestry System	Abundance		Shannon-Wiener index		Species Richness	
	Estimate	Adjusted p value	Estimate	Adjusted p value	Estimate	Adjusted p value
SAR-ASP	-1.5517	0.8535	-0.0042	0.9315	0.0286	0.9338
SPT-ASP	2.6034	0.6411	0.0024	0.9764	0.3143	0.0004
SPT-SAR	4.1552	0.3246	0.0067	0.8379	0.2857	0.0015

NB: *The 95% confidence intervals (Cis) represent the average within which the true mean species richness is likely to fall. They provide a measure of uncertainty and reliability for the observed values across the different agroforestry systems.*
SAR-Silvoarable; ASP- Agrosilvipasture; SPT- Silvopasture

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Woody plant species diversity under different AF systems

The Shannon-Wiener diversity index was higher for woody plant species under the silvoarable system (H'=2.8) followed by that of woody plant species under the silvopastoral system (H'=2.62). The agrosilvipasture system exhibited the lowest Shannon diversity index (H'=2.61). Simpson's diversity index was highest under the silvoarable system (D=0.924), followed by agrosilvipasture (D=0.889). The lowest Simpson's index (D=0.850) was exhibited under the silvopastoral system. The Simpson evenness value was highest for woody plants under the silvopastoral system (E= 9.00), followed by that under the agrosilvipasture system(E=9.00), and the silvoarable system exhibited the lowest evenness value (E= 6.68). Although there were differences in the species diversity among the three systems, these differences were not significant (p>0.05) based on the one-way ANOVA statistical test (Table 5).

The Tukey multiple pairwise comparison test for Shannon Wiener indices shows that for silvoarable and agrosilvipasture, the negative estimate (-0.0042) indicates silvoarable has a slightly lower diversity than agrosilvipasture, and the adjusted p-value (P=0.9315) indicates this difference is not statistically significant. Comparing the diversity between silvopastoral and agrosilvipasture, the estimate of 0.0024 indicates a slightly higher diversity in silvopastoral compared to agrosilvipasture, but the adjusted p-value (P= 0.9764) suggests this difference is not significant. For silvopastoral and silvoarable, the positive estimate (0.0067) reveals that the silvopastoral system has higher diversity than silvoarable, but the high adjusted p-value (P= 0.8379) again indicates this is not statistically significant (Table 4).

Table 5 details the diversity indices for woody plant species under different agroforestry systems studied in Kabingo Subcounty. It provides a summary of the Shannon-Wiener, Simpson, and Simpson's Evenness indices, which are crucial metrics for assessing diversity within each system. These indices reflect the ecological richness and evenness of the woody plant species, providing insights into the overall health and stability of the ecosystems.

Table 5. Woody plant species diversity indices under different agroforestry systems

Agroforestry system	Diversity indices			F-value	P-value
	Shannon- Wiener	Simpson	Simpson's Evenness		
Silvoarable	2.80	0.924	13.1	0.1645	0.8484
Silvopastoral	2.62	0.850	6.68		
Agrosilvipasture	2.61	0.889	9.00		

Individual 95% CIs For Mean Based Pooled Std Deviation

Discussion

Species abundance under different agroforestry systems

The silvopastoral system exhibited the highest total count and mean abundance of woody plants. This could be attributed to the system's ability to maintain higher shrub and tree populations. Grebner *et al.* (2022) findings indicate that silvopastoral systems which combine woody plants with livestock grazing result in increased tree and shrub densities. This may be attributed to the multipurpose nature of these systems, in which trees are not only planted and maintained for their products but also contribute to providing shelter and fodder for cattle, resulting in a higher individual count when compared to silvoarable and agrosilvopastoral systems.

The agrosilvipasture system revealed a higher abundance than silvoarable but lower compared to the silvopastoral system. This could be attributed to a greater diversity of components within the agrosilvipasture system. This finding is in conformity with the study by Boinot *et al.* (2022) who indicates that agrosilvipasture systems, combining agricultural crops, trees, and pasture, might offer a more diverse habitat for a high number of woody plants. On the other hand, the lower mean abundance in the silvoarable system could reflect the impact of intensive agricultural practices, and the disturbances to woody plants in croplands which Lawson *et al.* (2019) suggest can reduce tree abundance.

Despite these differences in mean abundance and total count, the one-way ANOVA test indicated that the differences in species abundance across the three systems were not statistically significant (p > 0.05). This finding aligns with Esquivel *et al.* (2023), who also reported non-significant differences in woody plant species abundance among various agroforestry systems, emphasizing that variations mostly occur based on a combination of factors such as systems management. This lack of significant difference might be attributed to similar ecological and environmental conditions. This aligns with research by Bedane *et al.* (2023), which suggests that factors such as

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management practices, soil fertility, and climate conditions might also play crucial roles.

Furthermore, the Tukey multiple pairwise comparison test showed that whereas there are statistical differences in mean abundance between the systems, none of the differences reached statistical significance. This could imply that the factors influencing species abundance are complex and not solely dependent on the type of agroforestry system, supporting the findings of Boinot *et al*. (2022), who noted that species distribution and abundance could be influenced by a myriad of factors beyond just the agroforestry system type, hence implying that variability in mean abundance within agroforestry systems might be observed but not always to a statistically significant degree.

The predominance of species such as *Euphorbia tirucalli* across all systems could reflect their resilience and adaptability to different environmental conditions, and its being a pioneer plant within the savanna ecosystem as Hastilestari *et al*. (2013) observed in their study on species adaptability in various agroforestry practices. Species such as *Combretum molle*, *Carica papaya*, and *Eucalyptus grandis* also showed higher abundance across the systems. This pattern might reflect the adaptability and resilience of these species to the conditions present in these agroforestry systems.

The findings imply that the factors influencing woody plant species abundance are complex, and therefore there is a need for further research to unravel these complexities. This could involve more detailed assessment of the microenvironmental conditions, soil characteristics, and management practices within each system, as these factors could significantly impact species abundance and distribution, as discussed by (Bedane *et al.,* 2023).

Species richness under different agroforestry systems

The silvopastoral system exhibited the highest species richness and this could be attributed to the structure of these systems, which combine tree and pasture elements. Such systems are known for creating diverse habitats and microclimates favorable for a variety of species. This finding is in line with the study by Sales-Baptista and Isabel (2021), who highlighted that silvopastoral systems often support higher richness due to varied strata of vegetation, the integration of different trophic levels, and the ability to attract seed dispersing agents due to various life forms such as birds. Furthermore, Choudhary and Rijhwani (2021) emphasizes that silvopastoral systems can increase the diversity of birds and other seed dispersing agents especially within savanna ecosystems, hence creating opportunities for diversifying woody plant components in such systems.

The species richness observed in the silvoarable system, though lower than in silvopastoral systems, is notable. This result aligns with research by Moreno *et al.* (2014), who argued that the integration of trees into arable lands can enhance biodiversity compared to monoculture systems but might still be less diverse than systems where pasture is integrated as pastures barely compete with woody plants. The lower species richness in the agrosilvipasture system could be due to the specific management practices or ecological conditions prevailing in the studied area. Boinot *et al.* (2022) noted that the impact of agroforestry on biodiversity is highly context-specific, depending on factors such as tree species selection, management intensity, and landscape context.

The statistical analysis revealing significant differences in species richness among the three systems, particularly between silvopastoral and the other two systems, reveal the unique ecological characteristics of each system. This finding is in conformity with research study by Schwarz *et al.* (2021), who emphasized that differences in biodiversity across agroforestry systems are often significant and influenced by the structural and functional complexity of each system.

The lack of a significant difference in species richness between the silvoarable and agrosilvipasture systems could mean that the elements of crop production and tree integration in both systems might have similar influences on biodiversity. This aspect might benefit from further research, considering the importance of crop diversity and tree-crop interactions in determining species richness, as pointed out by (Moreno *et al.,* 2014).

Diversity of woody plants under different agroforestry systems

The Shannon-Wiener diversity index, which considers both the abundance and evenness of species, was highest for the silvoarable system (H’=2.8), followed by the silvopastoral system (H’=2.62) and lowest in the agrosilvipasture system (H’=2.61). These findings suggest a higher diversity of woody plant species in the silvoarable system, contrary to what might be expected given the intensive agricultural practices associated with such systems. This finding is in conformity with research by Boinot *et al.* (2022) who highlight that silvoarable systems can increase species richness or diversity compared to traditional cropland. This suggests that the practice of silvoarable agroforestry can have a positive impact on biodiversity, even more so than in other types of agroforestry systems.

According to Zhao *et al*. (2022), the Shannon-Wiener index is sensitive to the presence of rare species, which might explain the higher diversity in the silvoarable system as it may have supported a range of species, including those less abundant. However, the Simpson’s diversity index, which gives more weight to the abundance of the most common species, was also highest in the Silvoarable system (D=0.924), indicating not just a variety of species but also a

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significant presence of common species. This could be attributed to the flexible nature of silvoarable systems, as noted by Lawson *et al*. (2019), who highlights that these systems support a variety of management approaches. Although competition between crops and woody plants can occur, improving how resources are used can help in reducing this competition and create a more balanced system.

The Simpson evenness value, highest in the silvopastoral system (E= 9.00), indicates a more uniform distribution of species within this system. This observation aligns with research by Moreno *et al.* (2014), who noted that silvopastoral systems could foster evenness due to their structured integration of trees and pasture, which might support a more balanced ecosystem. Despite these variations, the non-significant differences in diversity indices across the systems ($p>0.05$) as evidenced by the Tukey multiple pairwise comparison test suggest that whereas there are observable differences in diversity and evenness, these differences are not substantial enough to be statistically distinct. This outcome might indicate that other factors, such as local environmental conditions and specific management practices, could play a more critical role in determining species diversity than the type of agroforestry system alone.

The results challenge some traditional perceptions about agroforestry systems. For instance, the silvoarable system, typically considered less conducive to biodiversity compared to other agroforestry systems, has the highest diversity indices, which calls for a re-evaluation of how these systems are viewed in terms of biodiversity support. As emphasized by Boinot *et al.* (2022), the conservation potential of agricultural landscapes, including silvoarable systems, may be underestimated. These findings emphasize the critical role of agroforestry systems as landscape stabilizers in Uganda's rapidly transforming savanna zones. Given increasing land fragmentation (Herrmann *et al*., 2014), agroforestry configurations can buffer ecological degradation while contributing to spatial planning under Uganda's NDCs.

CONCLUSION

This study highlights the ecological significance and species diversity of woody plants within three distinct agroforestry systems i.e. silvoarable, silvopastoral, and agrosilvipasture across smallholder farms in Kenya. This research indicates the value of localized knowledge combined with digital tools for biodiversity documentation through integrating both field-based and tech-assisted species identification methods, including PlantNet-supported assessments and taxonomic validation. The comparative analysis revealed variability in tree and shrub composition across systems, reflecting differences in land-use objectives and ecological functions. These findings contribute to the understanding of landscape-level agroforestry dynamics and reinforce the potential of integrated systems to enhance biodiversity while sustaining livelihood.

Appendix

A. Appendix 1 *List of all woody plant species encountered in the floral diversity surveys in the three AF systems in Kyarugaju parish, Kabingo Subcounty, Isingiro district*

No.	Local Name	Scientific name	Family	Growth form
1	Payini	*Pinus caribea*	Pinaceae	Tree
2	Omurama	*Combretum mole*	Combretaceae	Tree
3	Karutusi	*Eucalyptus GU*	Myrtaceae	Tree
4	Ovacado	*Persea Americana*	Lauraceae	Tree
5	Omubirizi	*Vernonia amygdalina* Delile	Asteraceae	Shrub
6	Obugando	*Vachellia tortillis*	Fabaceae	Tree
7	Omugororo	*Dracaena fragrans* Ker Gawl.	Dracaenaceae	Shrub/Tree
8	Omuchungwa	*Citrus sinensis*	Rutaceae	Shrub/Tree
9	Karutusi	*Eucalyptus grandis*	Myrtaceae	Tree
10	Kasiya	*Senna spectabilis*	Fabaceae	Tree
11	Ekipapari	*Carica papaya*	Caricaceae	Tree
12	Fenensi	*Artocarpus heterophyllus*	Moraceae	Tree
13	Eipera	*Psidium guajava* L.	Myrtaceae	Tree
14	Omuyembe	*Mangifera indica*	Anacardiaceae	Tree
15	Kakawo	*Theobroma cacao* L	Malvaceae	Tree
16	Guruveliya	*Grevillea robusta*	Proteaceae	Tree
17	Musenene	*Thevetia peruviana*	Apocynaceae	Tree
18	Ekitooma	*Ficus natalensis*	Moraceae	Tree
19	Enkukuru	*Euphorbia candelabrum*	Euphorbiaceae	Tree
20	Entondiirwa	*Cajanus cajan*	Fabaceae	Shrub
21	Oruyenzhe	*Euphorbia tirucalli*	Euphorbiaceae	Tree
22	Omukuzanyana	*Melia azedarach*	Meliaceae	Tree
23	Mushambya	*Markhamia lutea*	Bignoniaceae	Tree

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No.	Local Name	Scientific name	Family	Growth form
24	Mangada	*Citrus Tangerina*	Rutaceae	Tree
25	Ekishogashoga	*Ricinus communis* L.	Euphorbiaceae	Shrub/Tree
26	Omusomoro	*Ficus sur*	Moraceae	Tree
27	Kasiya	*Senna bicapsularis*	Fabaceae	Shrub
28	Ekikunyu	*Ficus sycomorus*	Moraceae	Tree
29	Omukanja	*Rhus vulgaris* Meikle	Anacardiaceae	Shrub
30	Not identified	*Pyrus spinosa* Forssk	Rosaceae	Shrub
31	Murema	*Olea europaea* L.	Oleaceae	Tree
32	Omukiyovu	*Searsia natalensis*	Anacardiaceae	Shrub/Tree
33	Not identified	*Acacia senegalensis*	Fabaceae	Shrub/Tree
34	Omusikizi	*Euclea divinorum* Hiein	Ebenaceae	Shrub
35	Obugando	*Vachellia nilotica*	Fabaceae	Tree
36	Omuhanga	*Maesa lanceolate* Forssk	Myrsinaceae	Shrub/Tree
37	Enkomamahanga	*Punica granatum* L.	Punicaceae	Shrub
38	Omunyeganyegye	*Sesbania sesban*	Fabaceae	Shrub/Tree
39	Omugango	*Solanecio manii*	Asteraceae	Shrub/Tree
40	Kabunda	*Aleurites moluccana*	Euphorbiaceae	Tree
41	Omukarara	*Flueggea virosa*	Euphorbiaceae	Shrub/Tree
42	Ekyishekashekye	*Clerodendrum capitatum*	Lamiaceae	Tree
43	Obunyamahwa	*Citrus limon*	Rutaceae	Tree
44	Omunywamizi	*Voacanga thouarsii*	Apocynaceae	Shrub/Tree
45	Omushasha	*Macaranga kilimandscharica*	Euphorbiaceae	Tree
46	Lusina	*Leucaena leucocephala*	Fabaceae	Shrub/Tree
47	Omukoma	*Grewia mollis*	Malvaceae	Shrub/Tree
48	Omucungwa	*Citrus aurantifolia*	Rutaceae	Shrub/ Tree
49	Omutyaza	*Acacia sieberiana*	Fabaceae	Tree
50	Omushebeya	*Albizia gummifera*	Fabaceae	Tree
51	Omuboroboro	*Nuxia congesta*	Loganiaceae	Shrub/Tree
52	Ekinyamagosi	*Tabernaemontana pachysiphon*	Apocynaceae	Shrub/Tree
53	Omuzo	*Teclea nobilis*	Rutaceae	Shrub/Tree
54	Ekitugunda	*Vangueria madagascariensis*	Rubiaceae	Tree
55	Omuremampango	*Margaritaria discoideus*	Euphorbiaceae	Tree
56	Omubaruka	*Pittosporum spathicalyx*	Pittosporaceae	Shrub/Tree
57	Ekiko	*Erythrina abyssinica*	Fabaceae	Tree
58	Omudowa	*Neoboutonia macrocalyx*	Euphorbiaceae	Tree

B. Appendix II Woody plant species abundance under different AF Systems

Species	Silvoarable	Agrosilvipasture	Silvopastoral
Euphorbia tirucalli	12	82	157
Combretum molle	4	38	68
Carica papaya	30	24	14
Eucalyptus grandis	5	21	31
Vachellia tortillis	5	16	25
Ricinus communis	24	11	7
Senna bicapsularis	2	23	7
Mangifera indica	21	11	12
Persea Americana	18	13	5
Artocarpus heterophyllus	9	13	4
Senna spectabilis	2	12	7
Psidium guajava	10	4	7
Ficus natalensis	2	1	2
Vernonia amygdalina	1	2	1
Cajanus cajan	1	1	1
Grevillea robusta	19	0	5

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Species	Silvoarable	Agrosilvipasture	Silvopastoral
Citrus tangerine	1	3	5
Ficus sycomorus	1	2	1
Markhamia lutea	15	1	0
Vachellia nilotica	0	2	11
Thevetia peruviana	1	0	8
Grewia mollis	0	2	2
Citrus sinensis	3	1	0
Macaranga kilimandscharica	0	3	1
Ficus sur	24	0	0
Tabernaemontana	0	0	20
Citrus limon	0	0	20
Sesbania sesban	0	17	0
Vangueria madagascariensis	0	0	16
Erythrina abyssinica	0	11	0
Dracaena fragrans	10	0	0
Pyrus spinosa	0	0	4
Acacia sieberiana	0	0	4
Margaritaria discoideus	0	0	3
Voacanga thouarsii	0	0	3
Pinus caribea	3	0	0
Clerodendrum capitatum	0	0	2
Acacia senegalensis	0	0	2
Eucalyptus GU	1	0	0
Theobroma cacao	1	0	0
Euphorbia candelabrum	1	0	0
Melia azedarach	1	0	0
Rhus vulgaris	0	0	1
Olea europaea	0	0	1
Searsia natalensis	0	0	1
Euclea divinorum	0	0	1
Maesa lanceolata	0	0	1
Punica granatum	0	0	1
Solanecio manii	0	1	0
Aleurites moluccana	0	0	1
Flueggea virosa	0	1	0
Leucaena leucocephala	0	1	0
Citrus aurantifolia	0	0	1
Albizia gummifera	0	0	1
Nuxia congesta	0	0	1
Teclea nobilis	0	0	1
Pittosporum spathicalyx	0	0	1
Neoboutonia macrocalyx	0	0	1
TOTAL	**227**	**317**	**468**

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Conflict of Interest

There are no conflicts of interest declared by the authors.

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