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Enhancing on-farm species diversity through agroforestry practices: A study of Kitgum and Rakai districts of Uganda

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ABSTRACT

Agroforestry Practices are key to enhancing biodiversity and ecosystem services. This study investigated the effect of agroforestry practices on on-farm species diversity in Kitgum and Rakai districts of Uganda. We examined the socioecological factors influencing adoption, environmental benefits, and impacts on species diversity. Findings highlight climate and environmental gains, including rain enhancement and soil fertility, linked to agroforestry adoption. Results show that agroforestry practices support on-farm species richness, with nuances by district and practice. Given the absence of significant ANOVA results, differences in species richness may be more closely related to contextual factors than to the different types of agroforestry practices. While both districts demonstrated baseline species richness, the implementation of alley cropping in Kitgum was associated with higher numerical biodiversity scores.

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Introduction

Agroforestry is increasingly recognized globally for its role in food security, poverty eradication, climate mitigation, and biodiversity conservation (FAO, 2022). Research highlights its positive impact on household food security (Bader et al., 2023; Gold, 2023; Saqib & Khan, 2022) and its ability to enhance environmental co-benefits and crop growth (Baramee, 2020). In East Africa, these practices support livelihoods and plant diversity, shaped by various socioecological factors (Demie et al., 2024; Guzo et al., 2024; Kyazze et al., 2024; Tega & Bojago, 2023; Tesfay et al., 2024). Specifically in Uganda, agroforestry benefits livelihoods and is influenced by farmers' socioeconomic perceptions (Kumah et al., 2024; Turyamusiima, 2024). Building on recent Ethiopian studies regarding biodiversity (Demie et al., 2024; Masebo et al., 2024; Reshad et al., 2023), this study utilizes Margalef's Index and ANOVA to examine smallholder farmers' perceptions of agroforestry's role in supporting biodiversity within Uganda's Kitgum/Rakai context.

Materials and Methods

Area of Study

This study was conducted in Kifamba Sub-county, Rakai District (Figure 1), situated within the South-Western Rangelands Agro-Ecological Zone (SWRAEZ). To account for contextual variations, research was also carried out in Labongo Layamo Sub-county, Kitgum District (Figure 1), located in the Acholi sub-region of the Northern Agro-Ecological Zone (NAEZ). Kifamba Sub-county is located in the Central Region of Uganda. It shares borders with the districts of Lyantonde to the northwest, Lwengo to the north, Kyotera to the northeast, Kalangala to the east, Isingiro to the southwest, and Kiruhura to the northwest; it also borders the Kagera Region in the Republic of Tanzania to the south (Uganda Bureau of Statistics [UBOS], 2024a). Rakai Town, the district headquarters, is approximately 65.5 kilometers (40.7 miles) southwest of Masaka, the largest city in the sub-region. The area experiences a tropical wet and dry, or savannah, climate (UBOS, 2024a). According to the National Population and Housing Census (UBOS, 2024c), there are 3,765 households in Kifamba Sub-county and 2,669 households in Labongo Layamo Sub-county. Kitgum District lies between longitudes 32°E and 34°E and latitudes 02°N and 04°N. It borders South Sudan to the north, Karenga District to the east, Kotido District to the southeast, Agago District to the south, Pader District to the southwest, and Lamwo District to the northwest (UBOS,

2024b). The climate in Kitgum is characterized as warm with distinct wet and dry seasons (UBOS, 2024b).

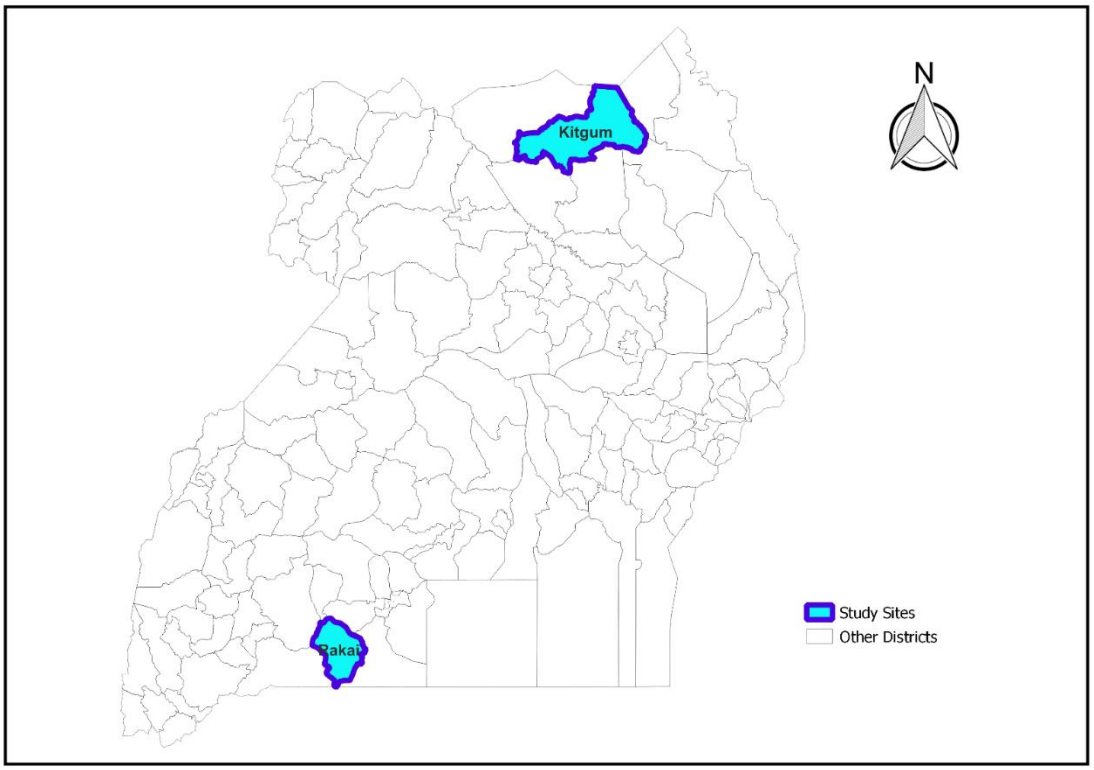

Figure 1. Uganda map showing districts with study areas

Research design

This mixed-methods cross-sectional study is guided by the philosophy of pragmatism and framed by the socio-ecological systems (SES) framework. This study addresses gaps in recent literature (Demie et al., 2024; Kumah et al., 2024; Tega & Bojago, 2024), which has underexplored the dynamic human–ecosystem interplay in agroforestry. Guided by pragmatist philosophy and the SES framework, we adopted a holistic, adaptive lens to examine agroforestry practices in the Kitgum and Rakai districts.

Sampling approach and technique

The sample size was determined using the Krejcie and Morgan formula (Krejcie & Morgan, 1970). We calculated the sample size (n). Assuming a 5% margin of error and 95% confidence interval, the sample size of Kifamba Subcounty is 349 households selected out of a population of 3765 households. The sample size of Labongo Layamo is 336 households selected from a population of 2,669 households. The survey included 685 households selected in a multistage sampling design.

In the first stage, we selected four rural parishes of Kabala (81), Kawunguli (93), Kifamba (84), and Kisaasa (91) in Kifamba subcounty. We also selected four rural parishes of Paibwor (67), Pamolo (84), Pagen (102), and Ocetoke (83) in the Labongo Layamo subcounty. In the second stage, we proportionately selected several villages from each of the eight selected parishes.

Data collection

Quantitative component

Data collection tools & data collected

We used a structured questionnaire with closed-ended questions to collect data on the tree species, crop species, livestock species, and agroforestry practices per selected household.

Qualitative component

We interviewed one focus group from Kifamba Sub-County (Rakai district) called Lutemi Njuki Terimba farming group (12 participants). We also interviewed one focus group from Labongo Layamo Sub-County (Kitgum District) called Pe – Opar farming group (9 participants). We happened to interview four key informants from Kifamba sub-county (a sub-county agricultural officer, and three parish chiefs from Kabala, Kawunguli, and Kisaasa parishes). We also interviewed four key informants from Labongo Layamo Sub-County (a senior assistant secretary – in charge of the Sub-County, an LC 2 chairman in Paibwor, and 2 parish chiefs from Pamolo and Ocetoke parishes). Data on experience with agroforestry, information sources, adoption motivations, benefits and challenges, and ecosystem services and biodiversity were gathered via key informant interviews and focus groups.

Data Analysis

Objective: Effect of agroforestry practices on on-farm species diversity

Gap: Insufficient understanding of smallholder farmers' perceptions regarding the contribution of agroforestry practices to on-farm species diversity (trees, crops, livestock) in Kitgum and Rakai districts.

Dependent variable: on-farm species diversity measured using Margalef's species index

Independent variables: We had two independent categorical variables: district (Rakai & Kitgum) and agroforestry practices (Silvopasture, Windbreaks, & agroforestry parklands) Species richness was calculated using the Margalef Index for each of the two districts (Rakai & Kitgum). One-way

ANOVA was applied to compare the means of Margalef indices among agroforestry practices in each of the districts. Finally, we performed a two-way ANOVA to establish the main effect of district, the main effect of agroforestry practice, and to test for an interaction effect between the two factors (districts and agroforestry practices). Initially, we had to calculate the Margalef Indices for both Kitgum & Rakai districts, where S is the number of species and N is the total number of individuals as follows:

Generate Margalef indices: = (S - 1) / log(N)

Followed by one-way ANOVA for each of the two districts. To calculate the ANOVA for the Margalef indices in Stata, we performed a two-way ANOVA, as we had two independent categorical variables: district (two levels) and agroforestry practices (three levels). First, we ensured our data was in a "long" format, where each observation had its own row, and there were separate columns for the calculated Margalef-index values, the district name/ID, and the agroforestry practice name/ID before running the Anova. The precision of this approach lies in capturing local agroforestry nuances while testing statistically robust differences. The study is context-specific; it fits the research question, and the local relevance is that the socioecological context has been mentioned.

Interpretation of ANOVA Results

The Stata output provided the ANOVA table. The precision of this table is that it shows the sum of squares, degrees of freedom, F statistic, and p-value for:

- The main effect of the district.
- The main effect of agroforestry practice.
- The interaction effect between district and agroforestry practice.

A significant p-value (typically < 0.05) indicates that there are statistically significant differences between the group means. The reverse is also true. We also applied the NVivo software for qualitative data analysis.

Triangulation

We used data validation triangulation, integrating quantitative and qualitative findings to validate results, identify convergence and divergence points, contextualize quantitative data, and refine key factors influencing agroforestry practices and on-farm species diversity. This approach is meant to boost confidence in results and minimize errors.

This is a cross-sectional study, guided by the pragmatist philosophy and framed by the socio-ecological systems framework.

Results

Quantitative results

The effect of agroforestry practices on on-farm species diversity was investigated in Rakai and Kitgum districts. Anova results (Table 1 & Table 2) showed no significant differences in species richness among agroforestry practices in either district.

Table 1. One-Way ANOVA Results for Species Richness in Kitgum District

Summary						
Groups	Count	Sum	Average	Variance		
Alley	3	9.7	3.233333	1.853333		
Wind	3	6.2	2.066667	0.723333		
Park	3	6.3	2.1	0.79		
Silvo	3	6.6	2.2	0.79		
ANOVA						
Source of variation	SS	df	MS	F	P-value	F crit
Between Groups	2.8067	3	0.935556	0.900294	0.482215	4.066181
Within Groups	8.3133	8	1.039167			
Total	11.12	11				

Table 2. One-Way ANOVA Results for Species Richness in Rakai District

Summary						
Groups	Count	Sum	Average	Variance		
Column 1	3	4.28	1.426667	0.148633		
Column 2	3	4.23	1.41	0.1225		
Column 3	3	6	2	0.25		
ANOVA						
Source of variation	SS	df	MS	F	P-value	F crit
Between Groups	0.6771	2	0.338544	1.948893	0.222761	5.143253
Within Groups	1.0423	6	0.173711			
Total	1.7194	8				

Anova Results for the main effect of district: p-value – 0.1408 (Are Kitgum and Rakai different overall – do they have different biodiversity levels regardless of the agroforestry practice), main effect of agroforestry practices: p-value – 0.6083 (do the practices - agroforestry parklands, windbreaks, silvopasture differ in impact – is silvopasture better than agroforestry parklands for biodiversity), and interaction effect: p – value – 0.7967 (does the effectiveness of a practice depend

on the district? – does alley cropping work better in Kitgum than it would in Rakai) showed no significant differences (Table 3)..

Table 3. Two-Way ANOVA Results for the Effects of District and Agroforestry Practice on Species Richness

Number of obs	18		R-squared	0.2493	
Root MSE	0.6861		Adj R-squared	-0.0634	
Source	Partial SS	df	MS	F	Prob>F
Model	1.8764278	5	0.37528556	0.80	0.5722
District	1.17045	1	1.17045	2.49	0.1408
Agroforestry	0.48787778	2	0.24393889	0.52	0.6083
District-Agroforestry	0.2181	2	0.10905	0.23	0.7967
Residual	5.6489333	12	0.47074444		
Total	7.5253611	17	0.4426683		

The data below was arranged in a long format, where each observation had its own row, and there were separate columns for the calculated Margalef index values, the district name ID, and the agroforestry name ID. This was done to be able to run the two-way ANOVA (Table 4).

Table 4. Long-Format Dataset Used for Two-Way ANOVA Analysis

district	agroforestry	Margalef	district2	agroforestry2	Agroforestry3
1	1	1.8	0	0	0
1	1	1.45	0	0	0
1	1	1.03	0	0	0
1	2	1.76	0	1	0
1	2	1.41	0	1	0
1	2	1.06	0	1	0
1	3	2.5	0	0	1
1	3	2	0	0	1
1	3	1.5	0	0	1
2	1	2.4	1	0	0
2	1	2.7	1	0	0
2	1	1.1	1	0	0
2	2	2.4	1	1	0
2	2	2.8	1	1	0
2	2	1.1	1	1	0
2	3	2.5	1	0	1
2	3	2.9	1	0	1
2	3	1.2	1	0	1

Margalef was calculated as $D = S - 1/\ln(N)$, where S is the number of species and N is the total number of individuals. Kitgum had 14 tree species, 16 crop species, 7 livestock species. It had 32,

247, 231, and 177 individual households for alley cropping, windbreaks, agroforestry parklands, and silvopasture consecutively. While Rakai had 11 tree species, 9 crop species, 7 livestock species. It had 251, 292, and 53 individual households for windbreaks, agroforestry parklands, and sivopasture consecutively (Table 5).

Table 5. Margalef Species Richness Indices by District and Agroforestry Practice

District	Practice	Trees	Crops	Livestock
Rakai	Windbreaks	1.8	1.45	1.03
Rakai	Agroforestry parklands	1.76	1.41	1.06
Rakai	Silvopasture	2.5	2	1.5
Kitgum	Alley Cropping	3.7	4.3	1.7
Kitgum	Windbreaks	2.4	2.7	1.1
Kitgum	Agroforestry parklands	2.4	2.8	1.1
Kitgum	Silvopasture	2.5	2.9	1.2

Qualitative Results

Experience and expansion (Adoption Dynamics and Spatial Constraints)

Smallholder farmers in both Kitgum and Rakai districts demonstrate a high level of conceptual alignment regarding the benefits of agroforestry. While there is a documented desire to expand these practices, limited land tenure and small plot sizes constitute the primary structural bottleneck. Participants expressed a clear intent to scale their agroforestry systems, but remain restricted by existing land boundaries.

Information sources/sources of knowledge (Knowledge Acquisition and Extension Pathways)

The acquisition of agroforestry expertise is characterized by experiential learning and horizontal knowledge exchange. In both districts, "learning by doing" and peer-to-peer sharing are the foundational methods for skill development. Respondents in Rakai specifically emphasized that collective action enhances the learning process. Farmers in Kitgum identified radio broadcasts as a critical secondary source, providing technical "tips" and specialized agricultural knowledge that complements traditional peer-led methods.

Motivations for System Adoption

The drivers for adopting agroforestry are multidimensional, spanning economic, social, and environmental spheres. Respondents in both regions cited household income stability, social

cohesion, and technical capacity building as primary motivators. A distinct motivational divergence was noted in Kitgum, where farmers expressed a strong commitment to intergenerational equity, viewing agroforestry as a necessary intervention for land preservation and the well-being of future generations.

Comparative Analysis of Benefits and Challenges

While the perceived benefits of agroforestry are largely universal across the study areas, the operational challenges are district-specific (Table 6).

Table 6. Comparative Analysis of Agroforestry Benefits and Challenges in Kitgum and Rakai Districts

Category	Kitgum District	Rakai District
Shared Benefits	Improved soil fertility, timber production, fodder, and wind protection.	Improved soil fertility, timber production, fodder, and wind protection.
Primary Challenges	**Production Hurdles:** Technical difficulties related to cultivation and tree maintenance.	**Market & Finance:** Limited access to credit facilities and stable commodity markets.
Unique Indicators	**Climate Resilience:** Trees are primarily viewed as a "shield" against climate volatility.	**Niche Income:** Barkcloth production serves as a vital revenue stream for educational expenses.

Ecosystem Services and Biodiversity

Smallholder farmers in the Kitgum and Rakai districts categorize agroforestry as a sophisticated integrated management system that systematically enhances on-farm biodiversity through the synergy of trees, crops, and livestock. This agricultural framework facilitates a synergistic scenario in which trees provide essential ecosystem services—including soil nutrient enrichment, micro-climate stabilization through shade, and the provision of livestock fodder—while simultaneously serving as critical windbreaks to protect underlying crops. Notably, farmers in Kitgum identify a direct correlation between tree density and hydrological regulation, characterizing deep-rooted vegetation as instrumental in local precipitation patterns. Ultimately, respondents across both regions perceive the farm as a mutually reinforcing biological unit where the presence of trees secures the necessary shelter and fertility for the entire agricultural ecosystem to thrive.

Discussion

Agroforestry Practices & Species Diversity

Margalef indices, indicative of species richness, varied across agroforestry practices and districts, suggesting that practice type and location influence species composition. Silvopasture in Rakai and alley cropping in Kitgum exhibited higher species richness, aligning with studies highlighting practice-specific impacts on biodiversity (Demie et al., 2024; Reshad et al., 2023). Notably, despite

the absence of a significant difference in species richness, variation across practices and districts underscores the importance of context-specific agroforestry strategies for optimizing biodiversity. This finding is consistent with Demie et al. (2024) and Reshad et al. (2023)**,** who reported practice-dependent variations in perennial plant diversity. Alley cropping in Kitgum likely contributed to its standout biodiversity scores, suggesting it's a game-changer for species mix.

Pragmatism Lens

Practical benefits: Silvopasture (Rakai) and Alley cropping (Kitgum) boost species richness, supporting food security, income, and ecosystems.

Tailored strategies: Different practices work in different contexts (e.g., alley cropping in Kitgum, Silvopasture in both Kitgum & Rakai).

Actionable takeaway: Promote context-specific agroforestry practices that enhance biodiversity and livelihoods. Introduce alley cropping to Rakai and see how it works.

Socio-ecological Systems (SES) Theory Lens

Socio-ecological interactions: Farmers' choices (social) shape on-farm ecosystems (ecological), influencing species diversity.

Feedback Loops: Effective practices (e.g., alley cropping in Kitgum) likely encourage farmers to maintain or expand them, enhancing resilience.

Context matters: SES highlights optimizing agroforestry practices for local conditions (e.g., Rakai vs. Kitgum) to support sustainability. This is to do with selecting suitable tree species, choosing appropriate agroforestry practices, and adapting management strategies to local needs and constraints.

District-specific Findings

In Kitgum, environmental benefits such as rain enhancement and improved soil fertility are balanced against production challenges, including pests, limited land, and a lack of capital, while Rakai's success depends on market access and financial resources (Demie et al., 2024; Reshad et al., 2023). These district-specific findings, consistent with Kumar et al. (2022) and Reshad et al. (2023), underscore that effective agroforestry outcomes require tailored, context-dependent strategies to manage socioecological complexities and ensure successful implementation (Demie et al., 2024).

Pragmatism Lens

Practical challenges: Kitgum's environmental benefits (e.g., rain enhancement, soil fertility) are offset by production hurdles (pests, inadequate land, lack of capital). While Rakai's success hinges on market access & finance.

Context-specific solutions: Interventions should address Kitgum's production constraints and Rakai's commercialization challenges.

Actionable Takeaway: tailor strategies to local needs; technical support for Kitgum, market linkages for Rakai.

Socio-ecological Systems (SES) Theory Lens

Complex interactions: Social factors (farmers' practices, market access) interplay with ecological factors (soil, pests), shaping outcomes.

Context-dependent: SES highlights how local conditions (Kitgum vs. Rakai) influence the effectiveness of agroforestry practices (Demie et al., 2024; Reshad et al., 2023)

Nuanced understanding: Grasping socioecological dynamics informs effective agroforestry implementation and scaling

Broader context

Agroforestry's potential for sustainable land use and biodiversity in Uganda is promising, given tailored approaches (solutions should fit each area's specific needs). As Uganda seeks to enhance food security and climate resilience, integrating district-specific agroforestry strategies could support livelihoods, conserve biodiversity, and mitigate environmental challenges. Globally, agroforestry is recognized for its ability to balance production and conservation. Uganda's context highlights the need for adaptive, localized practices (adjusting practices to suit local conditions, like climate, soil, market access, and community needs).

Conclusion

Agroforestry practices support on-farm species richness, with nuances by district and practice. Given the absence of significant ANOVA results, differences in species richness may be more closely related to contextual factors than to the different types of agroforestry. While both districts nailed the basics, Kitgum's extra move with alley cropping boosted biodiversity.

Recommendations

Agroforestry Practices & Species Diversity:

Implications:

. Policy: support practice-specific agroforestry extension services

. Research:

-explore why certain practices work better in specific contexts

-explore further into specific species composition (look closely at the tree species mix – which tree species, their roles, and how species-mix impacts biodiversity and productivity).

. Practice:

-Encourage farmers to adopt context-appropriate agroforestry practices for biodiversity and livelihood gains.

-Encourage farmers in the Rakai district to try the alley cropping agroforestry practice

- scale up practical learning: Leverage social/practical learning for agroforestry dissemination in both districts. That is, use the existing social networks and hands-on experience of smallholder farmers to spread agroforestry knowledge. Since the study found that smallholder farmers in both districts rely on practical and social learning, leveraging this could involve:

- Farmer-to-farmer training
- Field days and demonstrations
- Local farmer groups sharing experiences
- Building on existing social connections to promote agroforestry practices

District-specific findings:

Implications:

Policy: support context-specific interventions (e.g., pest management in Kitgum, market access in Rakai) -address district-specific challenges.

Extension: train farmers in optimizing practices for local conditions (e.g., in Kitgum, focus on drought-tolerant trees, space trees to balance shading and soil fertility benefits with crop yields). In Rakai, prioritize high-value fruits for market access.

Research: explore socio-ecological drivers of agroforestry success in different contexts.

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