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Agroforestry Knowledge, Information Pathways and System Configuration among Smallholder Farmers in Eastern Uganda

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Abstract: Agroforestry adoption among smallholder farmers is not merely a technical decision to plant trees, but a knowledge-dependent process shaped by information access, planting-material pathways, species choice and spatial farm design. This study examined agroforestry knowledge, information pathways, tree species distribution, seedling acquisition systems and agroforestry configuration among smallholder farmers in Iganga and Mbale districts of Eastern Uganda. A socio-economic survey design was used to collect quantitative data from 240 systematically selected household respondents, with 120 respondents drawn from each district. Data were obtained using a structured questionnaire covering socio-demographic characteristics, livelihood sources, agroforestry awareness, information channels, tree species grown, seedling sources, tree-crop-livestock integration, perceived benefits and spatial arrangements. The survey was complemented by focus group discussions, key informant interviews, direct field observations and secondary institutional information to strengthen triangulation. Quantitative data were analysed using descriptive statistics, cross-tabulations and chi-square tests of independence at $p < 0.05$, while qualitative information was analyzed thematically. Results showed significant district-level differences in respondent characteristics, agroforestry knowledge, information pathways, tree species composition, seedling sources and spatial structures. Agroforestry knowledge was substantially higher in Iganga than Mbale, indicating that local exposure and support systems were more influential than demographic factors alone. Information pathways were plural but uneven, combining online sources, workshops, extension officers, farmer groups, indigenous knowledge and farmer-to-farmer networks. Fruit trees dominated both districts, although Maesopsis eminii, Eucalyptus spp., Grevillea robusta, Ficus natalensis and other species showed clear spatial differentiation. Seedling supply relied heavily on neighbours' gardens in Iganga, whereas Mbale showed more diversified access through private nurseries and institutional sources. Integrated tree-crop-livestock systems and scattered trees were common. The study concludes that agroforestry uptake depends on the interaction of knowledge systems, quality germplasm access and locally fitted spatial configurations. Strengthening adoption requires integrated advisory services, reliable seedling systems and context-specific configuration support.

Keywords: Agroforestry; Eastern Uganda; knowledge pathways; seedling systems; system configuration.

INTRODUCTION

Agroforestry is now widely understood as a multifunctional land-use strategy in which woody perennials are deliberately combined with crops and/or livestock to produce ecological, economic and social benefits within the same farming landscape. Recent scholarship has moved beyond treating agroforestry as a single technology and instead presents it as a family of locally configured practices whose performance depends on species choice, spatial arrangement, management intensity, market incentives, tenure conditions and institutional support (Nair *et al.*, 2021; Duffy *et al.*, 2021; Tranchina *et al.*, 2024). This shift is important because smallholder farmers do not simply adopt trees; they fit trees into existing land, labour, crop and household livelihood systems. Systematic evidence shows that agroforestry can contribute to food security, income diversification, climate resilience, soil improvement and environmental stability, but these benefits vary across landscapes and are mediated by the capacity of farmers to access reliable knowledge, quality germplasm and supportive extension systems (Duffy *et al*., 2021; Zerihun, 2021; FAO, 2022; FAO, 2023; Tranchina *et al*., 2024). The current debate therefore places stronger emphasis on knowledge pathways and enabling conditions rather than on promotion of tree planting alone.

In sub-Saharan Africa, agroforestry has become central to discussions on climate-smart agriculture, restoration and rural livelihood resilience because many smallholder households face declining soil fertility, fragmented landholdings, high input costs, rainfall variability and limited non-farm income opportunities. Recent studies indicate that adoption is influenced by observable livelihood value, species compatibility with farming systems, access to seedlings, extension contact, farmer networks, market linkages and household assets (Buyinza *et al*., 2020; Kansiime *et al*., 2022; Fané *et al*., 2024; Shilomboleni, 2024; Begho, 2025). Yet the same literature also warns that agroforestry is not automatically beneficial when farmers plant poorly matched species, obtain low-quality seedlings, lack management advice or face competition between trees and annual crops (Galandi *et al*.,H2022; Tranchina *et al*., 2024; Bamwesigye *et al*., 2024). Evidence from Mali and Burkina Faso, for example, shows that preferred agroforestry technologies and species are shaped by household needs, crop yield expectations and local socio-economic conditions, while evidence from Uganda's Mt. Elgon region shows that farmer motivation to integrate trees is shaped by attitude, perceived behavioural control and social norms rather than technical information alone (Buyinza *et al*., 2020; Fané *et al*., 2024).

Knowledge and information pathways are especially important because agroforestry decisions are knowledge intensive. Farmers need to understand tree-crop compatibility, pruning requirements, spacing, seedling quality, product uses, likely economic returns and risks associated with pests, shade, labour and tenure. Contemporary agricultural advisory literature shows that extension and advisory services increasingly operate through mixed systems involving public extension officers, farmer groups, farmer-to-farmer networks, indigenous knowledge, radio, mobile phones, online sources and private input providers (Kansiime *et al*., 2022; Yang *et al*., 2022; FAO, 2023; Begho, 2025; Gwelo, 2025). These pathways are not interchangeable. Digital tools can widen access where farmers have devices, connectivity and literacy, but may reinforce inequality where older, poorer or less connected farmers are excluded (Kansiime *et al*., 2022; Gumbi *et al*., 2023; FAO, 2023). Farmer networks can increase trust and accelerate diffusion, but they may also circulate incomplete or localised information unless connected to technical advisory services (Yu *et al*., 2024; Begho, 2025). Consequently, studying agroforestry knowledge requires attention to the plurality, reliability and local fit of information sources.

Eastern Uganda provides an important empirical setting for this analysis because the region contains contrasting smallholder farming contexts where tree integration is shaped by population pressure, land fragmentation, topography, livelihood needs and institutional histories. Uganda's recent agroforestry literature emphasises the role of youth engagement, indigenous knowledge, extension access, market incentives and farmer motivation in shaping adoption, while also identifying restricted assistance and training opportunities as constraints to wider uptake (Buyinza *et al*., 2020; Kalanzi *et al*., 2021; Bamwesigye *et al*., 2024; Kyazze *et al*., 2024). In the Mt. Elgon area, local tree knowledge and project-based support have been shown to influence how farmers interpret tree benefits and integrate trees with coffee and other farming activities (Buyinza *et al*., 2020; Kalanzi *et al*., 2021). However, less is known about how knowledge sources, seedling acquisition pathways, species composition and spatial arrangements vary between contrasting districts such as Iganga and Mbale. This gap matters because interventions that assume a uniform information environment may fail to match farmer realities.

This paper therefore examines agroforestry knowledge, information pathways, tree species distribution, seedling sources and system configuration among smallholder farmers in Iganga and Mbale districts of Eastern Uganda. Its contribution is threefold. First, it provides district-level evidence on the knowledge systems through which farmers encounter and interpret agroforestry. Second, it links species and seedling patterns to the practical institutional and social pathways that make tree planting possible. Third, it evaluates the spatial configurations through which farmers fit trees into crop and livestock systems under smallholder conditions. The paper is guided by the argument that agroforestry uptake should be interpreted as an integrated socio-technical process, not simply as a binary adoption outcome. This approach strengthens the evidence base for designing locally appropriate extension, seedling supply and agroforestry configuration strategies for Eastern Uganda.

MATERIALS AND METHODS

Study Location

The study was conducted in Iganga and Mbale districts of Eastern Uganda (Figure 1). The two districts were purposively selected because they represent contrasting agroforestry and smallholder production contexts within the same broad region. Iganga is predominantly lowland and strongly agrarian, with relatively stable resident farming households and mixed crop-livestock systems. Mbale, located within the wider Mount Elgon agro-ecological context, is characterised by higher population pressure, more intensive land use and greater exposure to soil conservation and tree-based livelihood interventions. The comparative design allowed the study to examine whether agroforestry knowledge, seedling pathways and spatial configurations differed under contrasting local conditions.

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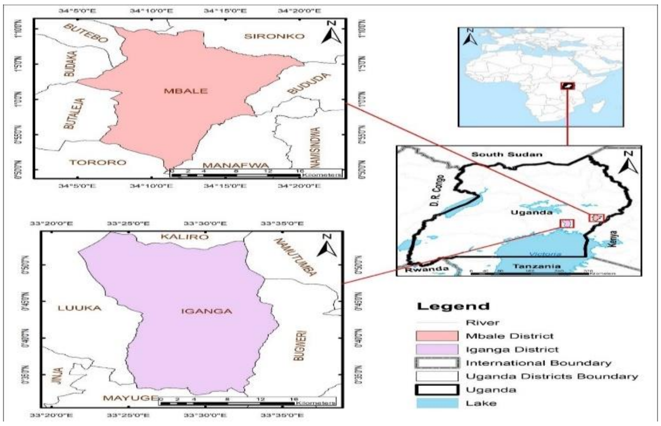

Figure 1: Map of the study area- Iganga and Mbale districts, Eastern Uganda

Data Collection

A socio-economic survey design was adopted because the study sought to quantify household-level knowledge, practices and agroforestry system attributes while also capturing farmer explanations behind the observed patterns. The target population comprised smallholder farming households engaged in crop and/or livestock production. A systematic sampling procedure was used to select 240 household respondents, with 120 respondents drawn from each district. The equal district allocation was intended to support direct comparison between Iganga and Mbale and to reduce imbalance in cross-tabulations. Household respondents were adults involved in farm decision-making, tree management or crop-livestock production activities.

Primary quantitative data were collected using a structured household questionnaire. The instrument captured socio-demographic characteristics, main livelihood sources, agroforestry knowledge, sources of agroforestry information, tree species grown on farms, sources of seedlings and planting materials, tree-crop-livestock integration, perceived benefits of integration and spatial arrangements of agroforestry systems. The questionnaire contained closed-response items suitable for frequency analysis and cross-tabulation, while selected items allowed farmers to identify multiple sources or practices where applicable. This was important because farmers often rely on more than one information pathway, seedling source or spatial arrangement.

The household survey was complemented by focus group discussions, key informant interviews, field observations and secondary institutional information. Focus group discussions were used to capture shared explanations on agroforestry practices, preferred species, farmer knowledge and local reasons for spatial arrangements. Key informant interviews targeted stakeholders with knowledge of agroforestry extension, seedling systems, community mobilisation and local farming conditions. Field observations helped verify the presence of trees, farm arrangements and the practical integration of trees with crops and livestock. These qualitative sources were not used to re-estimate the numerical results; rather, they were used to triangulate the survey findings and strengthen interpretation.

Data Analysis

Quantitative data were coded, cleaned and analysed using descriptive statistics, cross-tabulations and chi-square tests of independence. Percentages were used to describe the distribution of respondent characteristics, livelihood sources, awareness, information pathways, tree species, seedling sources and spatial structures. Chi-square tests were used to assess whether selected categorical variables differed significantly between Iganga and Mbale, with significance assessed at $p < 0.05$. To avoid unnecessary duplication in the manuscript, separate chi-square tables have been collapsed into narrative statistical reporting within the results. Qualitative data were analysed thematically by identifying recurring explanations related to farmer learning, seedling access, species choice, farm layout and perceived benefits of agroforestry integration.

The study retained the respondent profile in the manuscript because demographic and livelihood characteristics provide necessary context for interpreting agroforestry knowledge and practice. Gender, age, education, marital status, household size and residence duration were considered especially relevant because they influence access to labour, information, land-use experience and decision-making authority. However, the analysis does not treat these variables as sufficient explanations on their own; instead, they are interpreted alongside district-level knowledge pathways, seedling supply mechanisms and system configurations.

RESULTS

This section presents the respondent profile and the results on agroforestry knowledge, sources of information, tree species, seedling sources and system configuration. The verified descriptive tables and figures have been retained, while separate chi-square tables have been collapsed into text to improve readability and reduce repetition.

Socio-demographic characteristics of respondents

The socio-demographic profile of the 240 sampled households is presented in Table 1. The profile indicates that respondents differed across districts in gender, age, education, marital status, household size and period of residence, all of which provide important background for interpreting agroforestry knowledge and system configuration.

Table 1: Socio-demographic characteristics of respondents in the two study areas

Characteristics	Attributes	Iganga (%)	Mbale (%)
Gender	Male	56.7	39.2
	Female	43.3	60.8
Age category (years)	18-35	11.7	25.8
	36-45	22.5	34.2
	46-55	20.0	18.3

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	56-65	29.2	17.5
	Above 65	16.7	4.2
Education level	Non-formal	16.7	11.7
	Primary	60.8	51.7
	Secondary	18.3	35.0
	Tertiary	2.5	0.8
	University	1.7	0.8
Marital status	Single	1.7	10.0
	Married	83.3	75.0
	Divorced	5.0	6.7
	Widowed	10.0	8.3
Household size	1-4	21.7	30.8
	5-9	48.3	57.5
	>=10	30.0	11.7
Period of stay in the area (years)	1-10	9.2	45.0
	11-20	10.0	16.7
	>20	80.8	38.3

District differences were statistically significant for gender (χ^2 = 7.38, df = 1, p = 0.0066), age category (χ^2 = 21.89, df = 4, p < 0.001), education level (χ^2 = 9.54, df = 4, p = 0.049), marital status (χ^2 = 8.14, df = 3, p = 0.043), household size (χ^2 = 12.55, df = 2, p = 0.0019) and residence duration (χ^2 = 48.63, df = 2, p < 0.001). Iganga had more male respondents, older farmers, larger households and longer-term residents, while Mbale had more female respondents, a younger respondent profile and a larger share of newer residents. These differences indicate that the two districts represent distinct smallholder social contexts rather than duplicate farming populations. Respondents reported varying sources of livelihood (Figure 2).

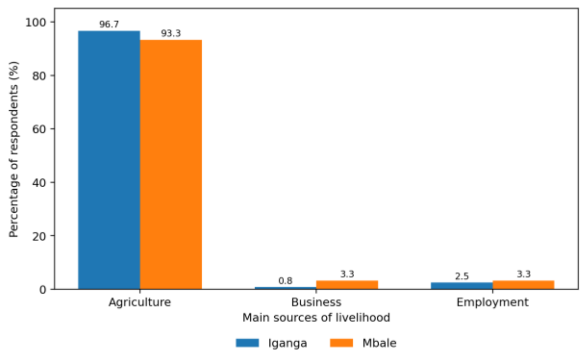

Figure 2: Main sources of livelihood among respondents in the study area

Agriculture was the dominant livelihood source in both districts, accounting for 96.7% of respondents in Iganga and 93.3% in Mbale. Business and formal employment accounted for only small proportions of respondents, indicating that both districts were strongly agrarian and that agroforestry decisions were made within farming-dependent livelihood systems.

Agroforestry knowledge among respondents

Farmers were first asked whether they had prior knowledge of agroforestry practices. Knowledge was markedly higher in Iganga, where 97.5% of respondents reported prior knowledge, compared with 57.5% in Mbale. The association between district and agroforestry knowledge was statistically significant (χ^2 = 57.9, df = 1, p < 0.001), showing that agroforestry awareness differed strongly by location. By contrast, gender (χ^2 = 0.253, df = 1, p = 0.615), age (χ^2 = 8.371, df = 4, p = 0.079), education (χ^2 = 1.483, df = 4, p = 0.830) and residence duration (χ^2 = 4.918, df = 2, p = 0.086) were not significantly associated with knowledge of agroforestry (Figure 3). This indicates that district-level exposure and support systems were more important than individual demographic characteristics in explaining awareness differences.

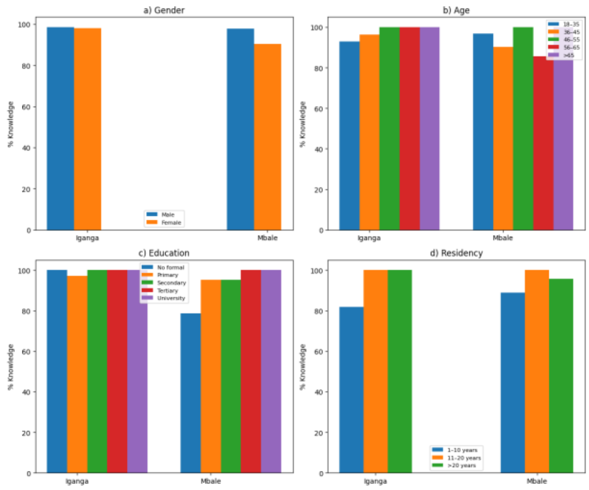

Figure 3: Clustered comparative distribution of respondents with knowledge of agroforestry across demographic groups in Iganga and Mbale districts

The disaggregated results show that knowledge levels remained consistently high across demographic groups in Iganga. In Mbale, knowledge was lower across most categories, although middle-aged and longer-term resident respondents tended to show somewhat higher levels of awareness. These patterns suggest that agroforestry knowledge is partly embedded in local exposure histories and community-level learning environments. Likewise, different sources of agroforestry knowledge were revealed in the study area (Table 2).

Table 2: Sources of agroforestry information among respondents in the study area

Source of knowledge	**Iganga (%)**	**Mbale (%)**
Training workshops	25.8	28.3
Online sources	33.3	3.3
Extension officers	5.8	7.5
Farmers' groups	11.7	18.3
Indigenous knowledge	21.7	5.8
Farmer-to-farmer networks	17.5	0.8

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The sources of agroforestry information differed significantly between districts for training workshops (χ^2 = 13.23, df = 1, p = 0.00028), online sources (χ^2 = 6.28, df = 1, p = 0.0122), extension officers (χ^2 = 19.88, df = 1, p < 0.001), farmers' groups (χ^2 = 4.86, df = 1, p = 0.027), indigenous knowledge (χ^2 = 11.38, df = 1, p < 0.001) and farmer-to-farmer networks (χ^2 = 18.07, df = 1, p < 0.001). In Iganga, the most common information source was online sources (33.3%), followed by training workshops (25.8%) and indigenous knowledge (21.7%). In Mbale, the most frequently reported sources were training workshops (28.3%), farmers' groups (18.3%) and extension officers (7.5%). The results indicate that knowledge dissemination was plural and district-specific, with Iganga relying more on digital and informal knowledge pathways and Mbale relying more on structured group and training-based channels.

Table 3: Sources of agroforestry knowledge by socio-demographic characteristics in Iganga and Mbale

Characteristic	Category	District	Training workshops (%)	Online sources (%)	Extension officers (%)	Farmer groups (%)	Indigenous knowledge (%)	Farmer-to-farmer networks (%)
Gender	Male	Iganga	35.3	36.8	7.4	10.3	13.2	19.1
	Male	Mbale	10.6	19.1	14.9	0.0	6.4	0.0
	Female	Iganga	13.5	28.8	3.8	13.5	32.7	15.4
	Female	Mbale	5.5	17.8	37.0	5.5	5.5	1.4
Age	18-35	Iganga	14.3	28.6	0.0	7.1	7.1	28.6
	18-35	Mbale	9.7	16.1	29.0	0.0	9.7	0.0
	36-45	Iganga	25.9	37.0	3.7	18.5	18.5	18.5
	36-45	Mbale	9.8	14.6	46.3	4.9	2.4	0.0
	46-55	Iganga	25.0	25.0	4.2	4.2	37.5	4.2
	46-55	Mbale	4.5	22.7	22.7	9.1	9.1	0.0
	56-65	Iganga	31.4	40.0	5.7	17.1	22.9	17.1
	56-65	Mbale	0.0	14.3	4.8	0.0	4.8	4.8
	>65	Iganga	25.0	30.0	15.0	5.0	15.0	25.0
	>65	Mbale	20.0	60.0	0.0	0.0	0.0	0.0
Education	Non-formal	Iganga	10.0	25.0	5.0	15.0	35.0	20.0
	Non-formal	Mbale	0.0	21.4	14.3	0.0	7.1	0.0
	Primary	Iganga	27.4	31.5	5.5	9.6	20.5	20.5
	Primary	Mbale	3.2	12.9	33.9	1.6	6.5	0.0
	Secondary	Iganga	31.8	45.5	9.1	18.2	13.6	9.1
	Secondary	Mbale	16.7	23.8	26.2	7.1	4.8	2.4
	Tertiary	Iganga	33.3	33.3	0.0	0.0	33.3	0.0
	Tertiary	Mbale	0.0	0.0	0.0	0.0	0.0	0.0
	University	Iganga	50.0	50.0	0.0	0.0	0.0	0.0
	University	Mbale	0.0	100.0	0.0	0.0	0.0	0.0
Residency	1-10 years	Iganga	36.4	27.3	0.0	0.0	0.0	27.3
	1-10 years	Mbale	5.6	11.1	50.0	3.7	5.6	1.9
	11-20 years	Iganga	8.3	8.3	0.0	16.7	50.0	16.7
	11-20 years	Mbale	20.0	35.0	30.0	5.0	0.0	0.0
	>20 years	Iganga	26.8	37.1	7.2	12.4	20.6	16.5
	>20 years	Mbale	4.3	19.6	2.2	2.2	8.7	0.0

Table 3 shows that information pathways were also differentiated within demographic groups. Male farmers in Iganga reported relatively high use of training workshops and online sources, while female farmers in Iganga reported greater reliance on indigenous knowledge and farmer-to-farmer networks. In Mbale, extension officers featured more strongly among female farmers and among respondents aged 36-45 years. Higher education levels were associated with more frequent use of online sources, while longer residence was associated with greater use of indigenous and peer-based knowledge. These descriptive patterns support the interpretation that agroforestry information systems are socially embedded and cannot be reduced to a single institutional source.

Tree species distribution and seedling sources

The study further examined the tree species grown (Table 4) and the sources from which farmers obtained tree seedlings and planting materials across the stud areas (Figure 4).

Table 4: Tree species distribution in the study area

Code	Tree species	Iganga (%)	Mbale (%)
1	Maesopsis eminii	70.8	5.8
2	Grevillea robusta	30.0	18.3
3	Eucalyptus species	10.0	25.8
4	Markhamia lutea	25.0	25.8
5	Pinus species	2.5	2.5
6	Fruit trees	93.3	79.2
7	Ficus natalensis	20.0	10.0
8	Albizia	1.7	7.5
9	Burthdavya nyasika (Improved mvule)	6.7	1.7
10	Khaya anthothea (Mahogany)	0.0	0.8
11	Terminalia superba (Umbrella tree)	0.0	2.5
12	Cupressus lusitanica	0.0	1.7
13	Cordia africana	0.0	0.8
14	Podocarpus ugandensis	0.0	0.8
15	Dovyalis caffra shrub	0.0	2.5
16	Prunus africana	0.8	0.0
17	Acacia	9.2	0.0

Fruit trees were the most common tree category in both districts, reported by 93.3% of respondents in Iganga and 79.2% in Mbale. Maesopsis eminii was highly concentrated in Iganga (70.8%) compared with Mbale (5.8%), while Eucalyptus spp. were more common in Mbale (25.8%) than in Iganga (10.0%). Grevillea robusta was more common in Iganga (30.0%) than Mbale (18.3%), while Markhamia lutea was similarly distributed across districts. Chi-square tests showed significant district differences for Maesopsis eminii (χ^2 = 112.36, df = 1, p < 0.001), Eucalyptus spp. (χ^2 = 9.21, df = 1, p = 0.002), fruit trees (χ^2 = 9.73, df = 1, p = 0.002), Grevillea robusta (χ^2 = 4.89, df = 1, p = 0.027), Ficus

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natalensis (χ^2 = 4.17, df = 1, p = 0.041), Albizia (χ^2 = 5.17, df = 1, p = 0.023), improved mvule (χ^2 = 3.94, df = 1, p = 0.047) and Acacia (χ^2 = 11.51, df = 1, p = 0.001). Species such as Markhamia lutea, Pinus spp., mahogany, Terminalia superba, Cupressus lusitanica, Cordia africana, Podocarpus ugandensis, Dovyalis caffra and Prunus africana did not show significant district differences.

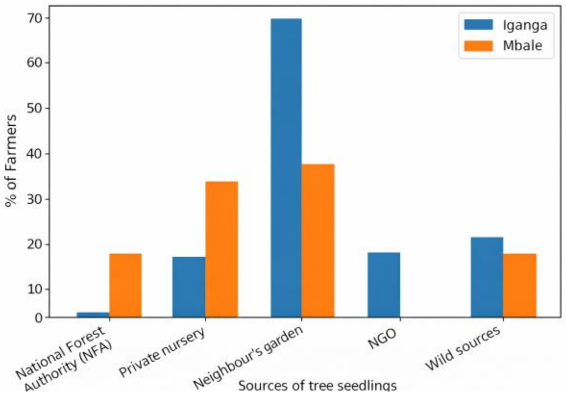

Figure 4: Sources of tree seedlings in Iganga and Mbale districts

Seedling sources also differed sharply across districts. In Iganga, neighbour's gardens were the dominant source of seedlings (71.7%), followed by wild sources (19.2%) and NGOs (15.8%). In Mbale, seedling access was more diversified: neighbour's gardens remained important (35.0%), but private nurseries (31.7%) and the National Forestry Authority (15.0%) also contributed. The use of seedling sources differed significantly for the National Forestry Authority (χ^2 = 15.417, df = 1, p < 0.001), private nurseries (χ^2 = 9.286, df = 1, p = 0.002), neighbour's gardens (χ^2 = 28.667, df = 1, p < 0.001) and NGOs (χ^2 = 20.000, df = 1, p < 0.001). Wild sources did not differ significantly between districts (χ^2 = 0.533, df = 1, p = 0.465).

Agroforestry system configuration and spatial structure

Agroforestry system configuration was assessed through whether farmers mixed trees, crops and animals within the same farm system. Integrated systems were dominant, with 90.4% of all respondents reporting that they mixed trees, crops and animals. The practice was more prevalent in Iganga (97.5%) than Mbale (83.3%), and the district difference was statistically significant (χ^2 = 12.310, df = 1, p < 0.001). Similarly, the benefits of mixing trees, crops and animals were enumerated (Table 5)

Table 5: Benefits of mixing trees, crops and animals in the study area

Benefit	Iganga n (%)	Mbale n (%)	χ^2	p-value
Increased income	99 (82.5)	81 (67.5)	6.422	0.011
Diversified food source	72 (60.0)	81 (67.5)	1.154	0.283
Improved soil fertility	35 (29.2)	47 (39.2)	2.241	0.134
Erosion control	10 (8.3)	43 (35.8)	24.797	<0.001
Provide shade	7 (5.8)	1 (0.8)	3.233	0.072
Provide fodder for animals	1 (0.8)	1 (0.8)	0.000	1.000
Provide manure	0 (0.0)	1 (0.8)	0.000	1.000
Provide fuel wood	3 (2.5)	1 (0.8)	0.254	0.614

Farmers identified several benefits of mixing trees, crops and animals. Increased income was the most frequently reported benefit, mentioned by 75.0% of all respondents, followed by diversified food sources (63.8%), improved soil fertility (34.2%) and erosion control (22.1%). District differences were significant for increased income, which was more frequently reported in Iganga, and erosion control, which was more frequently reported in Mbale. Other benefits, including diversified food, improved soil fertility, shade, fodder, manure and fuelwood, did not show statistically significant differences between districts. Table 6 represents the spatial structures identified in the study area.

Table 6: Agroforestry spatial structure in Iganga and Mbale districts

Spatial structure	Iganga n (%)	Mbale n (%)	χ^2	p-value
Boundary planting	34 (28.3)	14 (11.7)	9.401	0.002
Woodlot (trees only)	5 (4.2)	5 (4.2)	0.000	1.000
Alley cropping	6 (5.0)	7 (5.8)	0.000	1.000
Taungya	0 (0.0)	1 (0.8)	0.000	1.000
Home gardening	67 (55.8)	22 (18.3)	34.574	<0.001
Scattered trees on farm	83 (69.2)	79 (65.8)	0.171	0.679
Silvopastoral	3 (2.5)	0 (0.0)	1.350	0.245

Scattered trees on farms were the most common spatial arrangement, reported by 67.5% of respondents, followed by home gardening (37.1%) and boundary planting (20.0%). Boundary planting was more common in Iganga (28.3%) than Mbale (11.7%), and home gardening was much higher in Iganga (55.8%) than Mbale (18.3%). These differences were statistically significant for boundary planting and home gardening. Scattered trees, woodlots, alley cropping, taungya and silvopastoral systems did not differ significantly between the districts. However, respondents gave reasons for choosing different spatial structures (Table 7).

Table 7: Association between agroforestry spatial structures and generalized reasons for adoption in the study area

Spatial structure	Crop compatibility	Productivity enhancement	Income diversification	Food security	Soil fertility improvement	Land use efficiency	Protection (fencing)	Land constraint
Boundary planting	✓	✓	✓	–	✓	✓	✓	–
Woodlot (trees only)	–	✓	✓	–	✓	–	✓	✓
Alley cropping	–	✓	✓	✓	✓	✓	–	–
Taungya	–	✓	✓	✓	✓	✓	–	✓
Home gardening	✓	✓	✓	✓	✓	✓	✓	–
Scattered trees on farm	✓	✓	✓	✓	✓	✓	✓	–
Silvopastoral	–	✓	✓	✓	✓	✓	✓	✓

The association between spatial structures and reasons for adoption shows that productivity enhancement and income diversification were linked to all spatial structures. Soil fertility improvement and land-use efficiency were associated with most arrangements, particularly alley cropping, taungya, home gardening, scattered trees and silvopastoral systems. Food security was more prominent in home gardening, scattered tree, alley cropping, taungya and silvopastoral systems, while crop compatibility was mainly linked to boundary planting, home gardening and scattered trees. Protection was associated with boundary planting, woodlots, home gardening, scattered trees and silvopastoral systems, while land constraints were associated with woodlots, taungya and silvopastoral systems.

DISCUSSION

The first major finding is that agroforestry knowledge was substantially higher in Iganga than in Mbale, while gender, age, education and residency were not statistically significant predictors of knowledge in the pooled demographic comparisons. This finding indicates that awareness was shaped more by district-level exposure and knowledge infrastructure than by demographic attributes alone. A plausible explanation is that farmers encounter agroforestry through locally available information channels, projects, social networks and visible farm examples, which may differ across locations even when the farming populations share broadly similar agrarian livelihoods. This converges with Buyinza *et al*. (2020), who found in Uganda's Mt. Elgon region that farmer motivation to integrate trees was shaped by exposure to project interventions, attitudes and perceived control, suggesting that local opportunity structures matter. It also agrees with Kansiime *et al*. (2022), whose evidence from Kenya and Uganda shows that farmers obtain agricultural advice through multiple digital and non-digital sources, but that access remains uneven. Similarly, Fané *et al.* (2024) reported that agroforestry adoption in the Sudano-Sahelian zone was influenced by household and contextual characteristics rather than awareness alone. However, the current result partly diverges from older adoption assumptions that education and demographic characteristics are always dominant explanatory variables; here, education did not significantly differentiate knowledge once district context was considered. The critique is that awareness measures alone may overstate practical adoption readiness because knowing agroforestry does not necessarily mean farmers can access seedlings, manage tree-crop interactions or sustain trees over time.

The second finding is that agroforestry information pathways were plural and strongly district-specific. Iganga farmers relied more on online sources, indigenous knowledge and farmer-to-farmer networks, whereas Mbale farmers showed stronger association with training workshops, farmer groups and extension officers. This pattern suggests that agroforestry knowledge circulates through hybrid systems rather than a single extension pipeline. The explanation is that farmers combine formal, informal, digital and experiential knowledge depending on availability, trust, literacy, social connection and relevance to immediate farm decisions. This finding converges with Yang *et al*. (2022) and FAO (2023), who argue that agricultural advisory systems need to move beyond one-way extension and combine face-to-face, group-based and digital services. It also aligns with Begho's (2025) systematic review showing that farmer networks in sub-Saharan Africa disseminate information on improved practices, soil conservation and climate-smart agriculture, while Yu (2024) demonstrates that social networks can support learning and information diffusion among farmers. At the same time, the high use of online sources in Iganga must be interpreted cautiously because Kansiime *et al*. (2022) found that digital advisory access in Kenya and Uganda is constrained by digital literacy, affordability and device ownership, especially among women and older farmers. The critique is therefore that digital sources can widen information access but should not be treated as a substitute for technical extension unless mechanisms exist to verify information quality and include less digitally connected households.

The third finding is that information sources varied within demographic groups, with male farmers in Iganga using more workshops and online sources, female farmers in Iganga relying more on indigenous knowledge and peer networks, and female farmers in Mbale showing relatively stronger contact with extension officers. This finding suggests that agroforestry information systems are gendered and socially embedded, even when overall gender differences in agroforestry knowledge were not statistically significant. The likely explanation is that men and women may participate differently in training events, farmer groups, household decision-making, tree ownership and day-to-day farm management. This converges with Kiptot and Franzel's work on gendered agroforestry benefits and with recent Uganda-focused discussions emphasising gender and youth inclusion in agroforestry promotion (Bamwesigye *et al*., 2024). It also agrees with Kansiime *et al*. (2022), who found that female and elderly farmers were more likely to report digital advisory barriers. Recent work on endogenous knowledge and gendered species prioritisation also shows that local agroforestry preferences can differ by socio-demographic and agro-pedological contexts (Houndjo Kpoviwanou *et al*., 2024). A divergence is that this study did not find gender itself to be a statistically significant determinant of knowledge, which may mean that gender shapes pathways and benefits more than the simple yes/no measure of awareness. The methodological critique is that future studies should move beyond awareness and measure knowledge depth, decision authority and benefit control.

The fourth finding is that fruit trees dominated in both districts, while species such as Maesopsis eminii, Eucalyptus spp., Grevillea robusta, Ficus natalensis, improved mvule and Acacia were unevenly distributed across districts. This finding indicates that tree species composition is not random; it reflects livelihood needs, ecological suitability, planting material availability, farmer familiarity and market or household uses. Fruit trees likely dominate because they

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provide food, income and visible short- to medium-term benefits, making them more compatible with smallholder priorities. This converges with Duffy *et al*. (2021), who highlight the role of agroforestry in food access and income among smallholders, and with Zerihun (2021), who found that agroforestry practices contribute to livelihood improvement where farmers derive both economic and environmental benefits. The finding also aligns with Fané *et al*. (2024), who reported that farmers' preferred species and agroforestry technologies in West Africa were shaped by perceived positive attributes and household needs. In Uganda, Bamwesigye *et al*. (2024) similarly emphasise that species choice and management affect water use, competition and farmer incentives. The divergence lies in the strong concentration of Maesopsis eminii in Iganga, which suggests that local histories of seedling availability or farmer preference may produce highly specific species assemblages. The critique is that species popularity should not automatically be interpreted as technical suitability; some fast-growing or high-demand species may create shade, water or competition concerns unless their placement and management are well guided.

The fifth finding is that seedling acquisition was strongly district-specific. Iganga depended heavily on neighbours' gardens, while Mbale had a more diversified seedling system involving neighbours' gardens, private nurseries and the National Forestry Authority. This finding shows that planting material access is a central pathway through which agroforestry knowledge becomes practice. The explanation is that farmers are more likely to plant available, affordable and locally trusted seedlings, even if those seedlings are not genetically improved or technically ideal. This converges with Muchugi *et al*. (2022), who argue that tree crop planting material infrastructure in Africa varies by species, stakeholder involvement and propagation methods, and with Tranchina *et al*. (2024), who identify viable production technology, inputs and germplasm as important preconditions for agroforestry adoption. It also aligns with the Uganda Trees for Food Security project logic, which emphasised rural resource centres, quality germplasm and farmer capacity building as part of scaling agroforestry. However, the reliance on neighbours' gardens in Iganga raises concerns about seedling quality, genetic diversity and species-site matching, while the more institutionalised seedling pathway in Mbale may still be constrained by cost, distance or limited species diversity. The critique is that seedling systems should be evaluated not only by availability but also by quality, traceability, survival rates and alignment with farmer objectives.

The sixth finding is that integrated tree-crop-livestock systems were dominant, with 90.4% of respondents reporting that they mixed trees, crops and animals, and the practice was significantly more prevalent in Iganga than Mbale. This finding demonstrates that agroforestry in the study area is largely embedded in diversified smallholder production rather than isolated tree planting. The explanation is that smallholders use limited land to meet multiple objectives, including food, income, soil protection, shade, fuelwood and livestock-related needs. This converges with Nair *et al*. (2021), who emphasise the deliberate integration of woody perennials with crops and livestock, and with Duffy *et al*. (2021), who frame agroforestry as a pathway to food security and resilience. Zerihun (2021) similarly reports livelihood improvements associated with agroforestry practice, while Shilomboleni (2024) shows that African smallholder resilience strategies commonly combine livelihood diversification and natural-resource management. The divergence is that some benefits often emphasised in agroforestry literature, such as fodder and manure, were rarely mentioned by respondents in this paper. This may reflect either under-recognition of indirect benefits or the specific tree species and livestock management systems present in the study area. The critique is that farmer-reported benefits capture perceived value but may understate ecological services that are less visible or harder to quantify.

The seventh finding is that increased income and diversified food sources were the most frequently reported benefits of mixing trees, crops and animals, while erosion control was reported much more in Mbale than Iganga. This indicates that farmers evaluate agroforestry through both livelihood and environmental lenses, but the relative importance of each benefit varies with local conditions. Iganga's stronger emphasis on income may reflect the dominance of fruit trees and household-level livelihood diversification, while Mbale's stronger emphasis on erosion control may reflect slope, land pressure and soil conservation concerns in the Mount Elgon context. This finding converges with Duffy *et al*. (2021) and Zerihun (2021), who associate agroforestry with food access, income and environmental stability, and with Bamwesigye *et al*. (2024), who emphasise agroforestry's climate and soil-related potential in Uganda. It also aligns with Tranchina *et al*. (2024), who argue that adoption depends on recognising links between production, markets and policy. The divergence is that improved soil fertility did not differ significantly between districts, even though soil fertility is commonly promoted as a major agroforestry benefit. This may indicate that farmers perceive soil fertility benefits more slowly or less visibly than income and erosion control. The critique is that extension messages should not over-generalise agroforestry benefits; instead, they should connect specific practices and species to the benefits farmers already prioritise.

The eighth finding is that scattered trees were the dominant spatial arrangement, followed by home gardens and boundary planting, while woodlots, alley cropping, taungya and silvopastoral arrangements were relatively uncommon. Boundary planting and home gardening were significantly more common in Iganga than Mbale. This suggests that farmers favour flexible spatial arrangements that can be fitted into existing smallholder plots without requiring major land reallocation. The explanation is that scattered trees, home gardens and boundary planting allow farmers to integrate trees while reducing direct competition with crops and maintaining flexibility in land use. The observed agroforestry technologies align with previous findings from Uganda. In Central Uganda (Greater Mubende), the predominant farm forestry systems included woodlots, boundary planting, and scattered trees on farms

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(Galandi *et al*., 2022), demonstrating the widespread use of these technologies across different agroecological zones. Similarly, Kalanzi *et al*. (2021) identified boundary planting, intercropping, and woodlots as important agroforestry technologies in the eastern highlands of Uganda, while Kyazze *et al*. (2024) highlighted locally adapted agroforestry technologies in the Mt. Elgon region. Fané *et al*. (2024) likewise found that the technologies adopted by farmers reflect local preferences, resource availability, and the feasibility of implementation under prevailing environmental and socioeconomic conditions. The divergence is that alley cropping and silvopastoral systems, which are widely discussed in agroforestry literature, were rare in this study, suggesting that technically promoted systems may not be the most feasible under land, labour or knowledge constraints. The critique is that agroforestry programmes should prioritise adaptable designs that farmers can realistically manage rather than assuming that more formalised spatial models are always superior.

The final finding is that productivity enhancement and income diversification were associated with all spatial structures, while food security, soil fertility, land-use efficiency, protection and land constraints varied by arrangement. This indicates that farmers select spatial configurations strategically according to expected functions. Boundary planting and home gardens were linked to compatibility, productivity, income, soil fertility, land-use efficiency and protection, while woodlots and taungya were associated with land constraints and productive use of limited space. This converges with Tranchina *et al*. (2024), who emphasise that successful agroforestry depends on linking production, markets, knowledge and resource security, and with Bamwesigye *et al*. (2024), who argue that context-specific systems are needed to manage competition and support climate adaptation in Uganda. It also agrees with the broader view that agroforestry is multifunctional but locally variable (Nair *et al*., 2021; Duffy *et al*., 2021). A divergence from generic agroforestry promotion is that the same spatial arrangement may serve different functions across households and districts. The critique is that intervention design should begin with farmer objectives and spatial constraints, then recommend species and management practices, rather than beginning with a predetermined agroforestry model.

CONCLUSION AND RECOMMENDATIONS

This paper concludes that agroforestry knowledge and system configuration among smallholder farmers in Iganga and Mbale districts are shaped by district-specific knowledge pathways, seedling systems, species preferences and farm spatial arrangements. Awareness was much higher in Iganga than Mbale, but the results show that awareness alone is insufficient for understanding agroforestry uptake. Farmers relied on plural information systems involving online sources, training workshops, extension officers, farmer groups, indigenous knowledge and farmer-to-farmer networks. Tree species composition was dominated by fruit trees but differed significantly for several species, indicating that farmer choices reflected local livelihood needs, availability and ecological or institutional conditions. Seedling access was especially important: Iganga relied heavily on neighbours' gardens, while Mbale had more diversified access through private nurseries and institutional sources. Integrated tree-crop-livestock systems were common, and farmers used flexible spatial arrangements such as scattered trees, home gardens and boundary planting to fit trees into constrained smallholder plots.

The study recommends that agroforestry programmes in Eastern Uganda should avoid uniform promotion models and instead begin with district-specific diagnosis of information pathways, seedling access, farmer objectives and spatial constraints. First, extension actors should strengthen plural advisory systems by linking public extension officers, farmer groups, trusted lead farmers, local knowledge holders and digital platforms so that information is technically reliable and accessible to different farmer categories. Second, seedling supply systems should be improved through quality-assured community nurseries, stronger private nursery support, better linkage with the National Forestry Authority and farmer training on species-site matching, seedling selection and early tree management. Third, agroforestry messages should prioritise practical farm configurations that farmers already use, especially scattered trees, home gardens and boundary planting, while introducing more complex options such as alley cropping or silvopastoral systems only where land, labour and technical capacity permit. Fourth, species promotion should be function-based rather than generic: fruit trees should be supported where income and food security are priorities, while erosion-control and soil-conservation species should be targeted to landscapes where land degradation risks are high. Finally, future research should measure not only awareness but also knowledge depth, seedling survival, tree management quality, benefit control, gendered decision-making and long-term productivity outcomes.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The data supporting the results are contained in the verified PhD thesis results chapter. Additional anonymised data may be made available by the corresponding author upon reasonable request, subject to institutional and ethical requirements.

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