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Tree diversity and determinants of on-farm tree planting in Nepal's Terai Lowland

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Abstract On-farm tree planting is a widely practiced agroforestry strategy that enhances soil productivity, supports rural livelihood, and contributes to climate resilience. However, the diversity of on-farm tree assemblages and the socio-economic factors shaping farmers' planting decisions remain poorly documented in Nepal's lowland Terai region. This study aimed to (1) quantify tree species richness, evenness, and dominance across four planting contexts; home gardens, woodlots, farm boundaries, and intercrops and, (2) identify the demographic and socio-economic determinants associated with on-farm tree growing. Field inventory of farmland trees and household socio-economic surveys were conducted in Ward 3 of Kawasoti Municipality, Nawalparasi (East of Bardaghat Susta) district, Nepal. Tree diversity was assessed using the Shannon–Wiener index (H′), Simpson's dominance (D), and Pielou's evenness (J′). Binary logistic regression modeled the presence of on-farm trees against 15 socio-economic predictors. We recorded 2,350 trees across 36 species and 18 families, with *Melia azedarach* and *Tectona grandis* being the most abundant species. Overall farmland planting has moderate diversity (H′ = 2.10; J′ = 0.59; D = 0.20). Among four planting context home gardens exhibited the highest species richness, while intercrops showed the greatest tree abundance. Logistic regression revealed five significant predictors of tree presence: agroforestry extension (OR = 41.1), male-headed households (OR = 2.67), livestock units (OR = 1.49 per LSU), farm size (OR = 1.09 per 0.0338 ha), and fuelwood consumption (OR = 1.01 per 30 kg)). Diverse planting contexts maintain tree species richness and abundance, with home gardens as biodiversity hotspots and intercrops boosting tree numbers. These patterns indicate that farmers strategically allocate species based on space availability, household needs, and management priorities.

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Strengthening extension, addressing gender disparities, and aligning agroforestry practices with household needs can advance the development of multifunctional and species-rich agroforestry systems in in Nepal's Terai.

Keywords Agroforestry · Tree diversity · Tree abundance · Logistic regression · Biodiversity · Resilience

Introduction

Farmland tree planting is a common agroforestry practice that involves planting trees within agricultural fields or along the farm boundaries. In 2010, approximately 43% of farmlands globally contained at least 10% tree cover, highlighting the widespread integration of trees into agricultural landscapes (Zomer et al. 2016). In Nepal, this system has traditionally been practiced maintaining soil productivity and fulfilling the subsistence needs for timber, fodder, fuelwood, and other non-timber forest products, forming an indispensable component of rural livelihoods (Puri and Panwar 2007; Amatya et al. 2018; Derero et al. 2021Oli, 2017)

On Farm tree plantation yields broader ecological, social, economic, environmental and climate implications. Ecologically, diverse trees planted on farm assemblages enhance pest regulation, nutrient cycling, microclimate moderation, and overall system resilience against biotic and abiotic stresses (Derero et al. 2021; Owate et al. 2018; Ojha et al. 2023; Barua et al. 2020; Dahal et al. 2025). Also, farmland trees support biodiversity conservation, soil restoration, and water regulation, and help mitigate erosion, runoff, and localized flooding and acts as habitat and "green corridor" across agricultural landscapes (Young 1997; Pandit et al. 2014; Goparaju et al. 2020; WeEffect, 2019). From a climate perspective, it also contributes significantly to microclimate regulation, carbon sequestration, and resilience to droughts and temperature extremes (Zomer et al. 2016; Quandt et al. 2023; Dhyani et al. 2021; Abebaw et al. 2025; Subedi et al. 2022). Economically, these trees supply a range of products including wood, resin, honey, medicinal herbs that support household income diversification and improve food security (Atangana et al. 2014; Ghimire et al. 2024). Moreover, farm trees contribute to reduce household expenditure on fuelwood and fodder while reducing dependence on nearby forests (Pandit et al. 2014; Datta et al. 2024; Ghimire et al. 2024).

Globally, on-farm tree planting is also increasingly recognized as a multifunctional intervention that contributes simultaneously to climate-change mitigation under the Paris Agreement, United Nations Sustainable Development Goals particularly SDG 2 (Zero Hunger), SDG 5 (Gender Equality), SDG 13 (Climate Action), and SDG 15 (Life on Land) and Nepal's commitments expressed in Nationally Determined Contributions (United Nations 2015; Goparaju et al. 2020; Dhyani et al. 2021; Quandt et al. 2023). Nepal's Second NDC under Paris Agreement (UNFCCC 2015; Government of Nepal 2020) explicitly targets the maintenance of 45% national forest cover, and the expansion of tree cover on private and agricultural lands by 2030, positioning smallholder farmland tree planting as a strategic pathway toward both global and national climate and development targets. Documenting how diversity and adoption of on-farm trees vary across smallholder contexts is therefore essential for translating these global and national commitments into actionable household-scale policy.

In Nepal, under current management scenarios, national forests are estimated to supply approximately 1.7 million m^3 of timber while private forests contribute about 1.0 million m^3 annually to domestic markets. Imported timber continues to account for roughly one-quarter of total market demand (Dangi 2024; World Bank 2020). Farm-based tree planting is a longstanding practice that meets more than 65% of Nepal's timber demand and nearly half of fuelwood consumption (Oli et al. 2015). Smallholder farms integrate trees across four major planting contexts: home gardens, farm boundaries, woodlots, and intercrops. Home gardens consist of plots surrounding the residence and are managed by households to cultivate fruit trees, fodder species, and other plants for household-use. Farm boundaries typically include fast-growing or protective species planted for land demarcation or wind protection. Woodlots are generally managed for timber or fuelwood production whereas Intercrops involve scattered multipurpose trees retained within annual cropping systems.

Despite the recognized benefits of on-farm tree planting, the factors shaping tree diversity in

Nepal's lowland Terai remain insufficiently documented. Existing evidence is often anecdotal or site-specific, limiting understanding of how farmers allocate species across planting contexts and how these choices relate to household characteristics and resource needs. Previous studies show that tree diversity varies among contexts, with home gardens typically supporting higher species richness due to their mix of fruit, fodder, timber, and household-use species (Kabir and Webb 2008; Asfaw et al. 2015), whereas farm boundaries, woodlots, and intercrops generally contain fewer purpose-selected or scattered multipurpose species (Kewessa 2020). However, species richness alone does not capture variation in abundance or dominance, underscoring the need to integrate multiple ecological diversity metrics.

Most prior studies have focused either on species counts or on Nepal's mid-hill regions, where ecological and socio-economic conditions differ substantially from the Terai. Consequently, empirical evidence linking ecological diversity metrics with farmer-level decision-making remains limited for this agricultural heartland undergoing rapid land-use change. Moreover, socio-economic drivers mainly livestock ownership, fuelwood demand, gender roles, and access to agroforestry training have rarely been incorporated into quantitative models of on-farm tree diversity (Padullés Cubino et al. 2024; Blanchette et al. 2021). This limit the understanding of how household needs and agricultural constraints shape planting decisions.

To address these gaps, this study integrates tree inventory data with household socio-economic surveys in Kawasoti Municipality to (1) quantify species richness, evenness, and dominance across four planting contexts (home gardens, farm boundaries, woodlots, and intercrops) and (2) identify socio-economic factors associated with on-farm tree presence using binary logistic regression.

By combining context-specific ecological assessments with statistical analysis of socio-economic predictors, this research provides a Terai-focused evaluation of both the composition of on-farm tree systems and the factors associated with on-farm tree growing, contributing evidence To inform agroforestry extension and policy planning.

Methods and methodology

Study area

This study was carried out in Ward No. 3 of Kawasoti Municipality, Nawalparasi (East of Bardaghat Susta) of Western Nepal (27°32′N, 83°40′E) (Fig. 1). The municipality spans elevations from 600 to 1,800 m and lies within a subtropical monsoon climate, receiving an average annual rainfall of 1,761 mm and experiencing temperatures ranging from 5 to 48 °C (CBS, 2021). Population density is 801 persons km^{-2}, with an average household size of 3.76 and a literacy rate of 84.8%. Dominant vegetation includes *Shorea robusta*, *Dalbergia sissoo*, and *Melia azedarach* (Kunwar et al. 2020).

The study area was purposively selected to represent a typical Terai smallholder farming landscape characterized by diverse agroforestry practices, including home gardens, boundary plantings, woodlots, and intercropping systems. The ward comprises 3,194 households and a population of 12,012. Its active community forestry engagement and logistical accessibility facilitated field data collection.

Sampling design

The sampling frame comprised all 3,194 farming households in Ward No. 3. The required sample size was determined using Yamane's formula (Yamane 1967) at a ± 7% level of precision (Eq. 1):

$$n = \frac{N}{1 + N * e^2} = \frac{3194}{1 = 3194 * (0.071)^2} = 187 \quad (1)$$

where N represents the total number of farming households, e is the desired level of precision, and n is the sample size.

A simple random sampling approach was employed. Each household was assigned a random number using the RAND() function in Microsoft Excel, after which the list was sorted in ascending order and the first 187 households were selected for the survey. Field data were collected between 1 and 30 March 2024.

Household recruitment and ethical considerations:

Prior to data collection, permission was obtained from relevant local authorities. Selected households

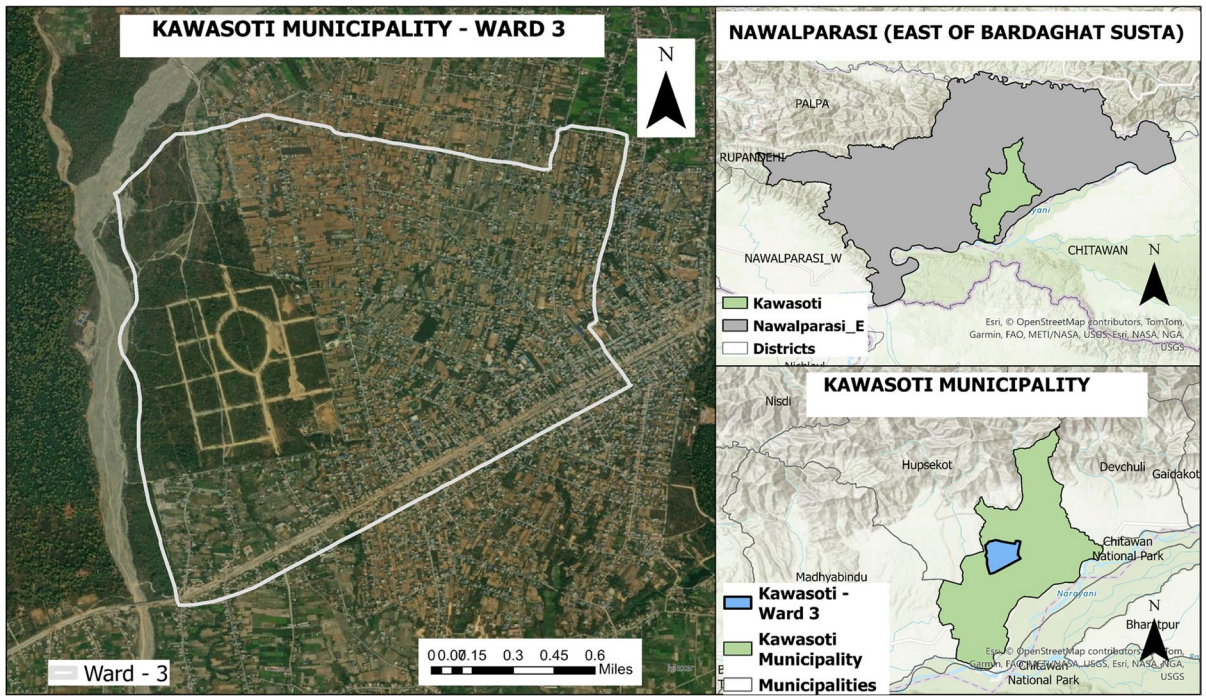


Fig. 1 Map of study area

were approached individually, and informed consent was obtained from the head of household or another adult household member. The consent process followed established ethical protocols (Ndayambaje et al. 2013). Participation was voluntary, and respondents were assured of confidentiality and anonymity. All data were handled in accordance with standard data protection practices.

Data collection

A mixed-methods approach was employed, integrating field-based tree inventory with household socioeconomic surveys during a single visit. Data were collected in March 2024 (dry season) to ensure clear visibility of trees and greater household availability during the agriculture post-harvest period.

Farm tree inventory

For this study, "farm trees" were defined as all woody perennials (excluding seasonal crops and ornamental species) located within farmland boundaries, including fields, farm boundaries, home gardens, and woodlots. All trees with a height ≥ 1.3 m were inventoried following the protocol described by Kharal and Oli (2009). Recorded attributes included vernacular and scientific names and estimated tree height. Unknown species were collected, pressed, and subsequently identified with the assistance of botanical experts.

Household questionnaire survey

A structured and semi-structured questionnaire, adapted from Albertin and Nair (2004), was administered to all 187 households through face-to-face interviews. The instrument captured information on household demographics, landholding and land tenure, income sources, natural resource use (fuelwood and fodder) and knowledge, attitudes, and motivations related to tree planting. The questionnaire was pre-tested with 15 households outside the study area to refine question clarity, sequencing, and survey length.

Key informant and focus group discussions

To triangulate and contextualize the quantitative findings, five key informant interviews were conducted with representatives from the Division Forest Office (DFO), the municipal agriculture office, the ward office, and local leadership and education sectors.

In addition, six focus group discussions (FGDs) were held, each comprising 8–10 farmers. Participatory methods recommended by the Poverty Environment Network (Angelsen et al. 2014) were employed. Discussions explored local perceptions of farm trees, planting constraints, access to extension services, and perceived changes over time.

Secondary data

Relevant secondary data sources: CBS (2021) census statistics, municipal records, Division Forest Office reports, and published literatures were consulted to provide contextual information, cross-validate primary data, and support the interpretation of findings.

Data analysis

Tree diversity and abundance analysis

Tree diversity on farmland was assessed using species richness (total number of distinct tree species) and tree abundance (total number of individual trees). Diversity analyses were conducted in R version 4.1.0 (R Core Team 2021) using the *vegan* package (Oksanen et al. 2020), while complementary statistical analyses were performed in STATA 14.2 (StataCorp 2015).

To capture multidimensional patterns of diversity, three commonly used ecological indices were calculated: the Shannon–Wiener diversity index (H′), Simpson's dominance index (D), and Pielou's evenness index (J′). These indices quantify overall diversity, species dominance, and distributional evenness, respectively.

In addition to overall farmland diversity, indices were computed separately for four primary planting contexts: home gardens, farm boundaries, intercropping areas, and woodlots. This stratified approach enabled comparison of compositional structure across agroforestry niches.

Species importance and functional use categorization

Dominant tree species were evaluated based on frequency of occurrence and individual abundance. Each species was further categorized according to its primary functional use, including fodder, fruit, timber, fuelwood, or multipurpose functions. Functional classifications were derived from household questionnaire responses, providing insight into farmer preferences and the ecosystem services associated with on-farm trees.

Demographic and socioeconomic variables

Fifteen explanatory variables were selected to examine socio-economic factors associated with on-farm tree presence (Table 1). The dependent variable (tree presence) was coded as a binary outcome. For analytical consistency, tree presence was defined as the intentional planting or active management of farmland trees within home gardens, boundary plantings, woodlots, or intercrop systems. Households containing only scattered, naturally occurring trees were classified as non-adopters (0). Thus, the binary outcome reflects purposeful agroforestry engagement rather than incidental tree occurrence.

The predictor variables comprised seven categorical and eight continuous variables (Table 1). Categorical variables included gender of household head, access to agroforestry extension services, education level, primary occupation, cooking energy source, land tenure status, and household income category. Continuous variables included age of household head, household size, total livestock units (LSU), total farm area (Hectare), farm-to-forest distance (minutes), distance to nearest market (km), and annual household consumption of fuelwood and fodder (kg).

All continuous predictors were tested for normality using the Shapiro–Wilk test. Variables with skewness > 1.0 were log-transformed to meet modeling assumptions.

Multicollinearity assessment

Before fitting the model, we tested for multicollinearity among explanatory variables using Variance

Table 1 List of predictor variables used in the model, their sources and measurement

No	Predictor variables	Description	Measurement	Sources	Expected sign
1	Gender	Gender of Household Head (HH)	0 = Otherwise, 1 = Male	Abate and Yohannes (2021), Abiyu et al. (2015), Kinuthia (2010), Melaku and Asfaw (2020)	+
2	Age	Age of HH	Continuous	Abiyu et al. (2015), Gebreegziabher et al. (2010)	+
3	Extension services	Any form of technical support including training, access to seedling access etc	0 = No 1 = Yes	Devkota (2022), Oeba et al. (2012)	+
4	Education	The highest education of the HH	0 = Illiterate 1 = Basic, 2 = Secondary, 3 = Bachelor's, 4 = Master's or above	Irshad et al. (2011), Khalwale et al. (2018)	+
5	Family size	Number of members in household	Continuous	Kinuthia (2010), Tadesse (2019)	+
6	Occupation	Main occupation of households	0 = Others 1 = Farm Based Occupation	Devkota (2022), Koirala (2022), Mutuku and Kiruki (2023)	+
7	Energy use	Energy used for cooking	0 = LPG 1 = Fuelwood, 2 = Biogas	Irshad et al. (2011)	+
8	LSU**	Total livestock unit owned by household	Calculated, See note	Tadesse (2019)	+
9	Land size	Total land owned by household (hectare)	Continuous	Kinuthia (2010), Melaku and Asfaw (2020), Mekonnen and Damte (2011), Oeba et al. (2012)	+
10	Land ownership	Gender of land title holder	0 = Otherwise, 1 = Male	Mutuku and Kiruki (2023)	+
11	Farm-Forest distance	Time to reach forest by household (*Minutes*)	Continuous	Oli et al. (2015)	+
12	Distance to Market	Distance to reach Markets by household (*km*)	Continuous	Abate and Yohannes (2021)	−
13	Fuelwood consumption	Annual Fuelwood Consumption (*kg*)	Continuous	Oli et al. (2015)	+
14	Fodder consumption	Annual Fodder grass Consumption (*kg*)	Continuous	Oli et al. (2015)	+
15	Household Income	Total monthly household income (NPR)	1 = NRs 30 -50 Thousand 2 = < 30 Thousand 0 = > 50 Thousand	Abate and Yohannes (2022)	−

Expected sign: + and − sign indicates the expected positive and negative relationship of predictor variables on tree growing on study area

** Livestock units (LSU) were calculated using the following conversion: 1 LSU = 1 buffalo = 1.2 cows = 4 goats = 5 sheep = 4 pigs = 2 calves (Otte and Chilonda 2003)

Inflation Factors (VIF) and tolerance statistics in Stata 14.2. Variables with VIF > 5 or tolerance < 0.20 were considered indicative of multicollinearity (Senaviratna and Cooray 2019).

Logistic regression modeling

We fitted a binary logistic regression model as specified in Eq. 2:

$$\ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n + \varepsilon i \quad (2)$$

where: Y is respondents' decision to adopt agroforestry (1 = yes, and 0 = otherwise), while the log odds ratio is denoted as ln [P/1 − P]. The remaining variables are described below:

β_0 = Model intercept (log-odds of tree presence when all X = 0.

β_1 to β_n = Estimated coefficients (log-odds change) for each explanatory variable.

$X_1,\ldots,X_n$ = Set of socio-economic predictors detailed in Table 1.

Logistic regression does not assume a normally distributed error term, so the ε_i term should be removed. Logistic regression assumes a binomial distribution with a logit link function.

The model was evaluated at significance thresholds of $\alpha = 0.10$, 0.05, and 0.01, consistent with prior agroforestry adoption studies (Abate and Yohannes 2021; Ibrahim et al. 2022; Mutuku and Kiruki 2023).

Model diagnostics

After fitting the logistic regression model, we evaluated model performance using three complementary diagnostic procedures (Hilbe 2011; Hosmer et al. 1989; Ibrahim et al. 2022).

1. Likelihood-ratio (LR) test

The log-likelihood of the full model (ℓ_1) was compared with that of a null model (ℓ_0, intercept-only) using the likelihood-ratio test statistic (Eq. 3)

$$x^2_LR_0 = -2(l_0 - l_1) \quad (3)$$

A p-value < 0.05 indicates that the fitted model explains significantly more variation than the null model. This test was performed in Stata 14.2 using the lrtest command.

2. Hosmer–Lemeshow goodness-of-fit test

Model calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow 1980). Observations were grouped into deciles based on predicted probabilities. Within each group, observed and expected frequencies were compared using the Hosmer–Lemeshow χ^2 statistic (Eq. 4).

$$\chi^2_{_HL} = \sum_{g=1}^{G} \frac{(O_{1g} - E_{1g})^2}{E_{1g}} + \frac{(O_{0g} - E_{0g})^2}{E_{0g}} \quad (4)$$

where O_1g and E_1g are the observed and expected successes in group g, and O_0g and E_0g are the failures.

This test was conducted in Stata 14.2 using estat gof, group(10). A non-significant p-value (p > 0.05) indicates adequate model fit.

3. Discrimination (ROC curve and AUC)

Model discrimination was evaluated using the Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC), following standard procedures described by Hanley and McNeil (1982). AUC values were computed using the *pROC* package in R (Robin et al. 2011). The AUC ranges from 0.5 (no discrimination) to 1.0 (perfect classification). A higher AUC value reflects better predictive performance.

Results

Tree species composition and abundance

A total of 2,350 individual trees, representing 36 species across 18 families, were recorded from 187 sampled farms with an average density of 12.6 trees per household and approximately 72 trees per hectare. The most abundant species were *Melia azedarach* (35.4%) and *Tectona grandis* (23.3%), followed by *Paulownia* spp. (11.9%) and *Mangifera indica*.

While *Melia azedarach* was the most abundant and frequently encountered species (present in 40.6% of farms), *Mangifera indica* ranked second in frequency, occurring in 30.5% of households. Other commonly reported species included *Psidium guajava* (Guava), *Carica papaya* (Papaya), *Litchi chinensis* (Litchi), and *Ficus semicordata* (Khanyu).

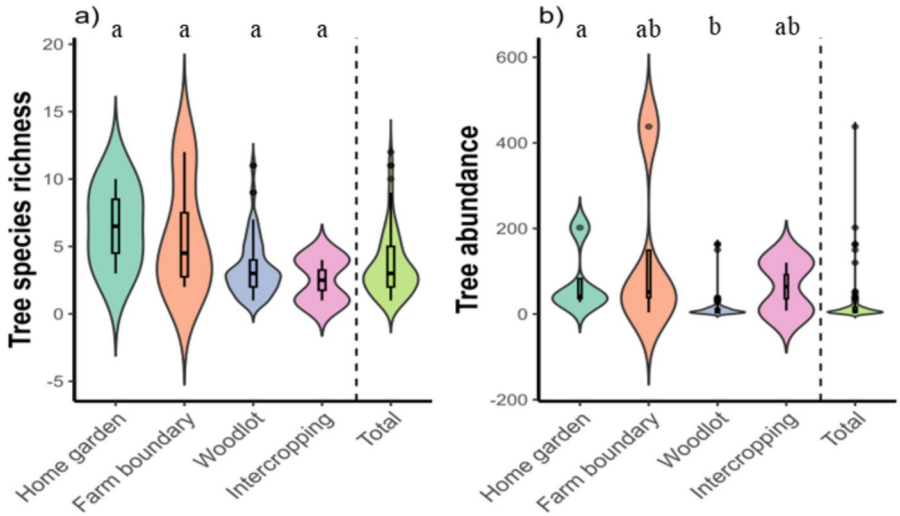


Fig. 2 Violin plots showing tree species richness **a** and abundance **b** across four farmland planting contexts. Different letters above each group indicate the result of Kruskal–Wallis test with post-hoc pairwise comparisons

Farmland tree species diversity and richness

Tree planting on farmland was organized across four dominant contexts: woodlots, farm boundaries, home gardens, and intercropping systems. The majority farmland trees were planted in woodlots (58.1%), followed by farm boundaries (23.2%), home gardens (13.3%), and intercropping systems (5.4%).

Home gardens exhibited the highest median species richness (6.5 sps.), followed by farm boundaries (4.5 sps.) and woodlots (3.0 sps.), while intercropping systems showed the lowest richness (2.5 species) (Fig. 2a). Home gardens and farmboundaries were dominated by fodder trees mainly *Melia Azaderach*, *Artocarpus Lakoocha* and *Morus Alba* and Fruit trees like *Mangifera Indica*, *Psidium Guajava* and *Litchi Chinensis*. Timber species, particularly *Paulownia tomentosa*, *Dalbergia sisso* and *Tectona grandis* were predominantly cultivated in woodlots. Intercropping systems were characterized by fodder species mainly *Morus alba* and fruit species mainly *Persea americana*.

A Kruskal–Wallis test indicated no statistically significant differences in species richness among planting contexts ($\chi^2_3 = 6.25$, $p = 0.100$). Subsequent Bonferroni-adjusted pairwise comparisons confirmed the absence of significant differences (Fig. 2a).

In contrast, tree abundance differed significantly across contexts ($\chi^2_3 = 14.83$, $p = 0.002$). Intercropping systems exhibited the highest median abundance (64 trees), followed by farm boundaries (51.5 trees) and home gardens (41 trees). Although woodlots accounted for the largest proportion of total trees recorded, they had the lowest median tree abundance per household (7 trees). Dunn's post hoc test with Bonferroni correction showed that woodlots supported significantly fewer trees per household than the other three contexts (adjusted $p < 0.05$), which did not differ significantly among themselves (Fig. 2b).

Tree diversity varied substantially among planting contexts (Table 2). Home gardens exhibited the highest Shannon–Wiener diversity index ($H' = 0.207$), reflecting a more even distribution of individuals across species despite moderate richness (26 species; 312 individuals). Farm boundaries followed with $H' = 0.145$, characterized by higher abundance but slightly lower evenness.

Intercropping systems showed comparatively low diversity ($H' = 0.088$), while woodlots exhibited the lowest diversity ($H' = 0.027$), with 1,365 individuals distributed among only seven species. This pattern reflects strong dominance of monoculture or low-diversity timber plantations in woodlots.

At the aggregate level, overall farmland tree diversity was moderate. The Shannon–Wiener index was $H' = 2.101$, compared to a theoretical maximum of $H'_{max} = 3.584$. Simpson's dominance index ($D = 0.202$) indicated limited overall dominance by any single species. Pielou's evenness index ($J' = 0.587$) suggested moderate distributional equality among species.

Table 2 Descriptive statistics for dependent variable and fifteen socio-economic predictors included in the binary logistic regression model

Panel A–Outcome			
Variables	Coding	Summary	Reference category
On farm tree planting	Yes	105 (56.15)	Tree absence and non-adopters
	No	82 (43.85)	

Panel B–Predictors					
1. Categorical variables			2. Continuous variables		
Variable	Coding	Frequency (%)"	Variable	Unit	Mean ± SD
Gender of HH (X_1)	Male	106 (56.68)	Age (X_8) of HH	Years	46.18 ± 11.96
	Female	81 (43.32)			
Extension services(X_2)	Yes	31 (16.58)	Family size (X_9)	Count	4.9 ± 1.59
	No	156 (83.42)			
Education of HH (X_3)	Basic	53 (28)	LSU(X_{10})		1.14 ± 2.24
	Secondary	91 (48.66)			
	Bachelor's	16 (8.56)	Land size (X_{11})	ha	0.18 ± 0.20
	Master's or higher	4 (2.14)			
	Illiterate	23 (12.30)	Time to forest (X_{12})	Minutes	18.66 ± 14.78
Occupation OF HH (X_4)	Agriculture	64 (34.22)			
	Others	123 (65.78)			
Energy used for cooking (X_5)	Fuelwood	26 (13.90)	Distance to market (X_{13})	Kilometres	4.26 ± 3.6
	Biogas	16 (8.56)			
	LPG	145 (77.54)	Fuelwood consumption (X_{14})	Kilograms	1,579 ± 2,815
Landownership title (X_6)	Male	104 (55.61)			
	Female	83 (44.39)			
Monthly household income (X_7)	NRs 30–50 Thousands	5 (2.67)	Fodder consumption (X_{15})	Kilograms	3,693 ± 15,662
	< NRs 30 Thousands	141 (75.40)			
	> NRs 50 Thousands	41 (21.93)			

Functional roles of on-farm trees

Farmland trees served multiple functional purposes. Most species were cultivated for fodder (15 species; 41.6%), followed by fruit production (13 species; 36.1%), timber (5 species; 13.9%), and fuelwood (3 species; 8.3%). In terms of annual supply contribution, farmland trees provided approximately 35% of fodder, 38% of fruits, 5% of timber, and 56% of fuelwood used by households.

Common fodder species include species like *Melia azedarach* (Bakaino), *Morus alba* (Kimbu), and *Ficus semicordata* (Khanyu). Species like *Mangifera indica* (Mango), *Carica papaya* (Papaya), and *Litchi chinensis* (Litchi) were widely cultivated for fruit production to household consumption and market sales. Timber-oriented species included *Tectona grandis* (Teak), *Paulownia tomentosa* (Paulonia), and *Albizia lebbeck* (Siris), often planted in farm boundaries or woodlots. Although fewer in number, fuelwood species like *Adina cordifolia* (Haldu), *Cinnamomum tamala* (Tejpat), and *Syzygium cumini* (Jamun) played an essential role in household energy supply.

Socio-Economic predictors of on-farm tree planting

Demographic and socio-economic characteristics

Of the 187 surveyed households, 106 (56.15%) were classified as actively growing trees on farmland, whereas 81 households (43.85%) did not intentionally plant or manage trees. In terms of ethnic composition, the sample was dominated by households

from the Brahmin/Chhetri group (71%), followed by indigenous groups (24%), including Gurung, Rai, Magar, Tharu, and Newar communities. The remaining 5% belonged to disadvantaged and marginalized caste groups, such as Dalit and Damai households.

Descriptive statistics for the dependent variable and fifteen socio-economic predictors are presented in Table 2.

Binary logistic regression was employed to examine socio-economic factors associated with intentional farmland tree growing. The dependent variable captured the presence (1) or absence (0) of purposefully planted or managed trees. Fifteen explanatory variables were included in the model (Table 3).

Significant Predictors

Five of the fifteen socio-economic predictors showed statistically significant associations with tree presence on farmland: extension services, gender, livestock units, farm size, and fuelwood consumption.

Extension services: In this study, 31% of the households received at least agroforestry extension services (Training, technical assistance, access to planting materials) through DFO, Agriculture Knowledge Center or other local NGOs. Extension services emerged as the single strongest determinant of growing farmland trees ($p = 0.001$). Controlling for all other factors, households receiving agroforestry-related extension services were 41 times more likely to grow trees on-farm than households that did not receive them (OR = 41.06).

Gender 56.68% of HH were male and remaining were females**.** Gender of HH was positively and significantly associated ($p = 0.033$) with trees growing on farmland at 5% level of significance. Male-headed households are about 2.67 times (OR = 167%) more likely to have trees on their farms compared to female-headed households.

Livestock unit Major live stocks were buffalo, cow and goats with an average 1.14 ± 2.24 LSU per household. LSU showed a significant positive effect on the odds of on-farm trees growing at the 10% level of significance ($P = 0.065$). Each additional livestock unit increased the likelihood of trees growing by approximately 49% (OR = 1.49). Although this effect did not meet the conventional 5% threshold, it points to the potential importance of fodder and livestock management in driving agroforestry practices.

Farm size Average size of the farm was 0.18 ± 0.20 ha. Larger landholdings significantly increased the likelihood of tree presence ($p = 0.029$). Every additional 0.0338 ha of land raised the probability of on-farm tree growing by approximately 9% (OR = 1.09 per 0.0338 ha).

Fuelwood consumption In this study, average annual fuelwood consumption was $1{,}579 \pm 2{,}815$ kg. 3 tree species were planted on-farm primarily for fuelwood use which fulfilled major chuck (56%) of annual fuelwood demand. The remaining fuelwood demand is covered through nearby community forest.

Fuelwood consumption was positively associated with tree-growing ($p = 0.046$; OR = 1.01 per 30 kg), suggesting that higher energy demands prompted on-farm tree cultivation for domestic fuel needs.

Non-significant predictors

In contrast, rest ten socio-economic variables including age and education of Household Head (HH), family size, primary occupation, cooking energy sources, land ownership, time to nearest forest, distance to market, fodder consumption and household income were not significantly associated with the presence of trees on farmland.

Age of household head The average age of HH was 46.2 ± 11.96 years. HH's age had a negative but non-significant effect on farm tree growing (OR = 0.99, $p = 0.614$). Each extra year of the HH's age corresponded to 1% decrease in the odds of managing on-farm trees.

Education of household head Majority of households had attained at least a secondary level of education, though 12.3% of household heads remained illiterate. However, none of the educational attainment categories exhibited a statistically significant difference in tree-growing behavior compared to the reference group of illiterate heads. Specifically, the odds ratios for Basic (OR = 0.76, $p = 0.716$), Secondary (OR = 0.53, $p = 0.378$), Bachelor's (OR = 0.28, $p = 0.210$), and Master's and above (OR = 0.47, $p = 0.590$) were all non-significant and had wide and overlapping confidence intervals reinforcing that formal education alone does not significantly shape tree-growing decisions in this landscape.

Table 3 Determinants of binary logistic regression predicting likelihood of farmland tree growing

S.N	Predictors(X_n)	Odds Ratio	Coefficient	Std. Err	Z	P- value
1	Gender of HH					
	Male	2.66552	0.9803	1.228913	2.13	0.033**
2	Age of HH	0.99017	−0.0095	0.019405	−0.50	0.614
3	Education of HH					
	Basic	0.761772	−0.2724	0.5687595	−0.36	0.716
	Secondary	0.530453	−0.6342	0.3811021	−0.88	0.378
	Bachelor's	0.279063	−1.2761	0.2842368	−1.25	0.210
	Masters	0.465086	−0.7651	0.6603661	−0.54	0.590
4	Family size	1.088861	0.0852	0.1393177	0.67	0.506
5	Occupation of HH					
	Agriculture	0.983346	−0.0167	0.4509149	−0.04	0.971
6	Cooking Energy Used					
	Fuelwood	2.557162	0.9381	1.766057	1.36	0.174
	Biogas	1.065097	0.6302	1.010223	0.07	0.947
7	LSU	1.488463	0.3971	0.320765	1.85	0.065*
8	Farm Size	1.092963	0.8881	0.044470	2.18	0.029**
9	Landownership					
	Male	1.921861	0.6531	0.8061615	1.56	0.119
10	Time forest (min)	0.993180	−0.0068	0.0145237	−0.47	0.640
11	Distance Market(Km)	1.063407	0.6147	0.0666275	0.98	0.326
12	Fuelwood Consumption	1.010014	0.0099	0.0050332	2.00	0.046**
13	Fodder Consumption	0.998680	0.0013	0.0009382	−1.41	0.160
14	Extension Service	41.05985	3.7150	44.650162	3.42	0.001***
15	Monthly Income					
	30–50 thousand NRs	0.0886527	−2.423	0.2371967	−0.91	0.365
	<30 thousand NRs	0.8748126	−0.133	0.4753814	−0.25	0.806
	Cons	0.1870297	−1.676	0.2573222	−1.22	0.223

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. HH = household head; LSU = livestock unit

Family size The average household size in the study area was 5 members. While each additional household member was associated with a 9% increase in the odds of on-farm tree growing (OR = 1.09), this relationship was not statistically significant (p = 0.506).

Primary occupation: Approximately one-third of households (34.22%) identified farm based occupations as their primary occupation, while the rest relied on alternative livelihoods such as overseas employment, business, or civil service. However, engaging in farm based occupations did not significantly influence the likelihood of on-farm tree planting (OR = 0.98, p = 0.971).

Cooking energy sources LPG was the most widely used energy source for cooking (77.54%) followed by fuelwood (13.90%) and Biogas (8.56%). While households using fuelwood appeared more likely to plant trees on farm than LPG user's (reference) (OR = 1.07), the effect was not statistically significant (p = 0.174). Also, Biogas users showed no appreciable difference of on-farm tree growing from those households using LPG (OR = 1.07, p = 0.947).

Land ownership 56% of land ownership was under male landowner. Households with male titled plots were approximately 1.92 times more likely to actively manage the trees on-farm compared to female-titled one (OR = 1.92). However, this relation was insignificant (p = 0.119), suggesting formal title gender alone does not play a decisive role in tree growing decisions.

Farm-Forest distance: Households were located on average 18.79 ± 14.80 min from the nearest forest. Each additional minute to the nearest forest slightly reduced odds of managing farmland trees

(OR = 0.993). However, the proximity to reach the forest was not significant (p = 0.640).

Distance to the market In the study area, Households were located on average 4.24 ± 3.62 km from the closest market. Greater remoteness conferred a modest but non-significant increase in odds (OR = 1.06 per km, p = 0.326) of managing farmland trees.

Fodder consumption The average annual fodder consumption was 3,693 ± 15,662 kg. 41.6% of tree grown on-farm were grown primarily for fodder production that provides 35% of fodder. Despite this, households consuming more fodder saw a slight, non-significant decrease in farmland tree growing (OR = 0.999 per 30 kg, p = 0.160).

Household income Majority of the households (75.40%) fall into lower income group (earning < 30 thousand NRs monthly) followed by higher income group (earning > 50 thousand NRs monthly) while the small percentage of remaining household were under middle income group (earning 30–50 thousand NRs monthly). Binary logistic regression showed that neither the lower income group (OR = 0.875, p = 0.806) nor the middle-income group (OR = 0.089, P = 0.365) differed significantly from higher-income households (reference).

Discussion

This study provides an integrated assessment of on-farm tree diversity and its socio-economic determinants in Nepal's Terai lowland, contributing to agroforestry literature by situating Terai systems within broader regional and global patterns while highlighting context-specific drivers of tree integration in intensively cultivated landscapes.

Tree species composition and abundance

Over half of the surveyed households maintained intentionally planted trees, with a mean density of 12.6 trees per household (72 trees ha^{-1}) indicating moderate but constrained tree integration within the Terai's predominantly agrarian landscape. These densities are comparable to those from Northeast India (86.3 stems ha^{-1}; Shukla et al. 2025) but substantially lower than values documented in Nepal's middle hills: 158 trees ha^{-1} in Tanahun (Oli et al. 2015), 188 trees ha^{-1} in Dhading (Baul et al. 2013), and 317 trees ha^{-1} in Chitwan (Regmi and Garforth 2010). More recently, Bhandari et al. (2021) documented 38 species across farm households in Tanahun and demonstrated that species diversity of trees outside forests varies significantly with landholding size and livestock ownership.

This gradient is not incidental. In the Terai, fertile alluvial soils incentivize intensive cereal and cash-crop cultivation, leaving limited spatial and economic room for tree integration. Mid-hill and mountain farmers, by contrast, depend on trees for slope stabilization, microclimate regulation, and diversified subsistence—functions that lowland farmers can partially substitute through market purchases or community forest access. Globally, irrigated lowlands tend to have lower tree cover than rainfed uplands (Zomer et al. 2016), a pattern consistent with the physiographic and socioeconomic contrasts identified by Baul et al. (2021a, 2021b). These findings reinforce that agroforestry promotion in the Terai must contend with the opportunity cost of land, and that strategies effective in the middle hills cannot be directly transferred without adaptation to lowland farming realities.

Farmland tree species diversity and richness

The 36 tree species from 18 families documented here are broadly consistent with Pokharel et al. (2022), who reported 35 species in the adjacent Nawalparasi district. However, species counts vary considerably across Nepal, from 20 in Sunsari (Das and Oli 2017) and 29 in Dhading (Webb and Dhakal 2011) to 38 in Tanahun (Bhandari et al. 2021) and 48 in Chitwan (Regmi and Garforth 2010), reflecting ecological and socio-economic heterogeneity. The comparatively lower richness relative to Chitwan likely reflects the Terai's stronger orientation toward intensive cereal farming, which constrains the spatial niche available for diverse tree species. Chitwan's longer history of community forestry engagement and proximity to protected areas may also expose farmers to a broader species pool and planting culture. More broadly, such variation mirrors findings from Derero et al. (2021), who showed that Ethiopian farmers diversify species to exploit multiple ecological niches and livelihood benefits as a strategy that requires both awareness and access to germplasm, conditions that vary across landscapes.

Diversity indices indicate a moderately diverse but unevenly distributed assemblage, consistent with global agroforestry norms (Magurran 2004). Shannon diversity was comparable to that reported by Devkota (2022) in Nawalparasi and aligned with regional patterns noted by Bhandari et al. (2021) and Pandey et al. (2021). However, species dominance was notably higher than that reported by Koirala (2022) in Nijgadh and Kolhabi. This likely reflects the commercial preference for a few fast-growing species particularly *Melia azedarach* and *Tectona grandis*, which together accounted for nearly 60% of all recorded trees, driven by their established market value and rapid returns. In Nijgadh and Kolhabi, a more subsistence-oriented management approach and greater reliance on naturally regenerated species may distribute abundance more evenly. This raises a critical concern: if market incentives continue to favor a narrow set of commercial species, compositional homogenization could erode the functional diversity that underpins household resilience. Nonetheless, the absence of overwhelming single-species dominance suggests a reasonably multifunctional tree community capable of buffering households against environmental shocks, pest outbreaks, or price volatility (Jamnadass et al. 2010; FAO, 2019).

Species richness and abundance also varied by planting context. Home gardens supported the highest richness, consistent with findings from central Nepal (Pandey et al. 2021) and mid-hill regions (Shrestha et al. 2018). This pattern reflects a domestic utility logic: households cultivate a mix of fruit, fodder, medicinal, and shade species near the homestead, where daily management is feasible and diverse needs converge. Woodlots, although accounting for over half of total trees, exhibited the lowest richness — an outcome of market-driven species selection, where farmers invest in timber species such as *Tectona grandis* and *Paulownia* spp. for predictable economic returns at the expense of variety, a trend also noted in Chitwan (Regmi and Garforth 2010) and Tanahun (Bhandari et al. 2021). Intercropping systems showed the highest abundance but lowest richness, suggesting that farmers retain a narrow set of compatible species at high density to minimize crop–tree competition while maximizing a specific function, typically fodder — a pattern echoing findings from East Africa (Avolio et al. 2015) and Northeast India (Shukla et al. 2025). Farm boundaries showed intermediate values, comparable to hedgerow systems described by Webb and Dhakal (2011).

Critically, while species richness did not differ significantly across contexts, tree abundance did, indicating that richness and abundance respond to distinct drivers. Cultural norms and household needs shape species choice, whereas land availability and production goals determine planting density (Degrande et al., 2006). This distinction carries practical implications: species-rich home gardens should be prioritized for smallholders seeking to maximize functional diversity on limited land, while boundary plantings and woodlots can be targeted toward larger landholdings that accommodate denser, commercially oriented tree populations.

Functional roles of on-farm trees

Most farm trees were planted for fodder (41.6%), followed by fruit (36.1%) and timber (13.9%), contributing 35%, 38%, and 5% of total household demand respectively. This functional emphasis reflects a deliberate risk-spreading strategy in which farmers select multipurpose, fast-growing species to balance subsistence and market needs (Ghimire et al. 2024; Derero et al. 2021).

Species preferences confirm this logic. *Melia azedarach*, *Mangifera indica*, and *Psidium guajava* dominated the study area, aligning with Devkota (2022) in Nawalparasi East. However, even within similar ecological zones, composition varied. *Garuga pinnata* and *Gmelina arborea* dominated in Chitwan (Kharal and Oli 2009) suggesting that local cultural preferences and market structures exert a strong filtering effect on species selection, independent of ecological suitability. Globally, similar patterns have been documented in Indian home gardens (Shrestha et al. 2018) and East African fodder-tree systems (Atangana et al. 2014), where species choices are embedded within household strategies that balance immediate livelihood needs with long-term ecological sustainability.

Socio-Economic predictors of on-farm tree planting

Binary logistic regression identified five significant and ten non-significant predictors. For interpretive clarity, we organize the discussion across four thematic domains.

Institutional support and access to knowledge

Extension services emerged as the strongest predictor of tree-growing: households that received agroforestry-related training or planting material were over 40 times more likely to plant or retain trees. This confirms that extension is foundational to adoption, consistent with Ahmad et al. (2023) in Pakistan and two Ethiopian studies: Ibrahim et al. (2022) on training attitudes and Gashu et al. (2025) on live fence and woodlot adoption. A global systematic review of 90 adoption studies similarly identified knowledge availability and technical support as among the most frequently cited adoption determinants (Tranchina et al. 2024), and Meijer et al. (2015) reported comparable patterns.

However, the magnitude of the odds ratio (OR = 41.06) warrants cautious interpretation. The high value may partly reflect the relatively small proportion of extension recipients (16.58%) in the sample, which can inflate odds ratios in logistic models. Moreover, the cross-sectional design cannot rule out reverse causality — households already inclined toward tree planting may actively seek extension services. Nevertheless, the direction of the effect is robust and policy relevant. Importantly, Houndjo Kpoviwanou et al. (2024) and Balehegn et al. (2015) found that training alone yields limited results when disconnected from material support or follow-up. The strong extension effect observed here reflects the integrated nature of local programming: combining training, seedling provision, and follow-up visits, reinforcing the value of well-designed, resource-backed extension.

Household resource base and production capacity

Farm size and livestock ownership both emerged as significant drivers. Larger farms had greater odds of tree planting, with each additional 0.0338 ha increasing the likelihood by approximately 9%, consistent with findings from Rwanda (Ndayambaje et al. 2013), Kenya (Nyaga et al. 2015), and global assessments (Mercer 2004). This reflects both the physical space and the economic flexibility that larger holdings provide for accommodating trees alongside crops. However, this also implies that smallholders who arguably stand to benefit most from diversified tree systems face a structural disadvantage, highlighting the need for space-efficient models such as enriched home gardens and boundary plantings.

Livestock holdings had a marginally significant effect, with each additional LSU increasing tree-growing likelihood by 49%. This reinforces the tree–livestock synergy documented by Oli et al. (2015) in Nepal's middle hills, Ahmad et al. (2023) in Pakistan, and a systematic review of agroforestry–livelihood linkages in East Africa (Muthuri et al. 2023). However, Balehegn et al. (2015) found no significant association between LSU and tree diversity where communal grazing areas and alternative fodder sources were available, suggesting that the livestock–tree relationship is context-specific that is shaped by land-use rights, climate, and access to alternative forage options. In the study area, where community forests supply only part of fodder demand, on-farm trees fill a critical gap, which likely explains the observed positive association.

by land-use rights, climate, and the availability of alternative grazing and forage options.

Livelihood needs and functional tree use

Fuelwood consumption had a small but significant positive effect. Although only 8.3% of trees were planted primarily for fuelwood, they contributed over half of household firewood needs, illustrating the indirect but pivotal role of energy demand in motivating tree retention. This aligns with findings by Webb and Dhakal (2011) and Gautam et al. (2009) in Nepal, who identified wood fuel dependency as a powerful driver of on-farm planting. Similarly, Krause et al. (2007) and Ndayambaje et al. (2013) highlighted fuelwood as a dominant household energy source driving farmers to integrate fast-growing species on farms, and Kulindwa and Ahlgren (2021) found tree planting in Tanzania strongly associated with perceived future woodfuel needs. Our findings suggest that fuelwood, though often a secondary product, remains a functional anchor of tree-growing decisions in the Terai. Extension programs should therefore incorporate multipurpose fodder and fuelwood species to leverage existing household energy demand as an entry point for agroforestry promotion.

Fodder consumption, by contrast, was not a significant predictor. Despite trees contributing 35% of fodder needs, households with higher consumption did not necessarily plant more trees likely because

community forests and grazing lands reduce on-farm pressure (Oli et al. 2015). This decoupling between consumption and planting behavior suggests that farmers view on-farm fodder trees as a supplementary rather than primary source, with planting decisions driven more by livestock ownership itself than by fodder volume consumed.

Demographic and locational characteristics

Gender was the only significant demographic predictor where male-headed households were 2.67 times more likely to plant or manage trees. This reflects structural disparities in land rights, decision-making authority, labor availability, and access to credit and extension which is consistent with findings from Kenya (Mutuku and Kiruki 2023), Nepal (Dhakal and Rai 2020), Malawi (Fisher and Kandiwa 2014), and Benin (Jésugnon Houndjo et al. 2025). Kiptot and Franzel (2012) and Kiptot et al. (2014) showed that women often participate substantially in agroforestry labor yet remain underrepresented in training and decision-making structures, and have limited control over tree products and income. These results underscore the need for gender-responsive interventions that empower female farmers through secure land rights, targeted training, and labor-saving technologies.

Other demographic variables: age, education, family size, occupation, income, and land title did not significantly influence tree-growing behavior. This aligns with Jenbere et al. (2012), Kinuthia (2010), Shackleton et al. (2008), and Devkota (2022), who found demographic attributes have limited influence once land access, institutional support, and production needs are accounted for. The non-significance of education is particularly notable, as several studies elsewhere have found positive effects (Irshad et al. 2011; Khalwale et al. 2018). In our context, this may reflect the localized nature of agroforestry knowledge transmitted primarily through extension and community networks rather than formal schooling—a hypothesis that warrants further investigation. Meanwhile, Gashu et al. (2025) and Dhakal and Rai (2020) reported that household size can influence planting decisions in labor-intensive contexts, and the absence of such an effect here may reflect the Terai's relatively lower labor demands for tree management compared to hill farming systems. These mixed outcomes underscore the high context dependency of demographic effects.

Similarly, distance to forests and markets had no significant effect, suggesting that relatively consistent institutional provisioning through community forests and DFO distributions attenuates spatial disadvantage. These results parallel Ali et al. (2024) in Bangladesh and Abiyu et al. (2015) in Ethiopia, who found mixed or negligible effects of spatial access on agroforestry adoption.

Practical implications for policy and implementation

The findings of this study translate into three concrete directions for policy and practice that align with both Nepal's national agroforestry framework and its commitments under international climate and biodiversity agreements.

First, the dominant role of extension services demonstrates that institutional support is the most effective lever for expanding on-farm tree planting in the Terai. Continuous, locally embedded agroforestry extension through Agriculture Knowledge Centers, Division Forest Offices, and Municipal Agriculture Sections backed by demonstration plots, planting-material supply, and farmer-to-farmer learning should be institutionalized as a core service rather than treated as a project-based intervention. This supports the implementation of Nepal's Agroforestry Policy 2019 (Government of Nepal 2019) and the farm-forestry component of the Forests for Prosperity Project (World Bank 2020) and contributes directly to SDG 13 (Climate Action) and SDG 15 (Life on Land) through enhanced tree cover and on-farm biodiversity (United Nations 2015; Dhyani et al. 2021).

Second, the significance of farm size, livestock holdings, and fuelwood consumption indicates that on-farm tree planting should be promoted as part of an integrated livelihood and energy strategy rather than as a stand-alone forestry intervention. Differentiated extension packages: fodder and livestock packages for medium-sized farms, fuelwood and fruit packages for fuelwood-dependent households, and species-diverse home-garden packages for smaller plots would better match the heterogeneous economic and biophysical realities of landowners. This approach aligns with the agriculture–forestry–livestock nexus framework increasingly emphasized in South Asian food-security policy (Datta et al. 2024; Ghimire et al. 2024). These

packages contribute directly to SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 7 (Affordable and Clean Energy) (United Nations 2015; Goparaju et al. 2020).

Third, the persistent gender gap in tree management where male-headed households are more likely to plant or manage trees calls for gender-responsive programming. Targeted training, secure tenure for women, women-led nurseries, and gender-disaggregated extension delivery would help close the participation gap and unlock the broader social and ecological benefits. This addresses SDG 5 (Gender Equality) and specifically Target 5.a on equal rights to economic resources including land ownership (United Nations 2015).

Taken together, these three directions speak directly to Nepal's Second Nationally Determined Contribution under the Paris Agreement (UNFCCC 2015; Government of Nepal 2020), which targets the maintenance of 45% national forest cover and the expansion of tree cover on private lands by 2030. Farmland tree planting of the kind documented here is one of the most cost-effective and scalable pathways toward that target (Nature-based Solutions Initiative 2022). Embedding agroforestry within Nepal's Long-term Strategy for Net Zero Emissions, integrating it into Local Adaptation Plans of Action (LAPAs), and aligning it with the Kunming–Montreal Global Biodiversity Framework's 30-by-30 target (CBD 2022) and the UN Decade on Ecosystem Restoration 2021–2030 (United Nations 2019) would operationalize multi-goal climate and biodiversity commitments at the household scale documented in this study.

Conclusion

This study provides a quantitative assessment of on-farm tree diversity and demographic and socioeconomic determinants of tree growing in Nepal's Terai lowlands. Across 187 farms, 36 species from 18 families were recorded at an average density of 72 stems ha^{-1}, reflecting moderate diversity ($H' = 2.10$, $J' = 0.59$, $D = 0.2021$). Species composition varied strongly by planting context: home gardens supported the highest richness, intercrops had the greatest abundance, and woodlots were comparatively sparse. Logistic regression identified five significant drivers of farmland tree growing: extension access, gender of household head, farm size, livestock holdings, and fuelwood demand while ten other socioeconomic variables showed no influence, indicating that household priorities and institutional support outweigh demographic attributes in shaping decisions.

Overall, our findings underscore the importance of context-specific agroforestry interventions, extension programs that combine hands-on training, follow-up support, farm resource endowments, and energy needs for promoting agroforestry adoption. And, encouraging multifunctional planting systems, especially species-rich home gardens and high abundance-boundary hedgerows, can enhance both biodiversity and ecosystem service delivery without compromising agricultural output. A key limitation of the study is its focus on one municipality and the use of cross-sectional data, which restricts broader generalization. The study also did not explore functional traits or longer-term ecological outcomes.

Beyond local relevance, the findings of this study link Nepal's smallholder farmland tree planting to multiple international policy frameworks. The biodiversity, food, fuel, and income functions of on-farm trees documented here advance six Sustainable Development Goals adopted under the 2030 Agenda (SDGs 1, 2, 5, 7, 13, and 15), while the carbon-sequestration and tree-cover dimensions support Nepal's commitments under the Paris Agreement (UNFCCC 2015), including its Second Nationally Determined Contribution (Government of Nepal 2020) and Long-term Strategy for Net Zero Emissions. Mainstreaming agroforestry into national climate finance, adaptation planning, and rural development budgets would translate these multifunctional benefits into measurable progress against globally recognized targets while strengthening household resilience in the Terai landscape.

Future research should evaluate the long-term ecological and economic impacts of these planting configurations, including carbon sequestration potential, soil fertility effects, and market linkages for tree products. Additionally, longitudinal and policy-linked studies are essential for designing scalable, resilient agroforestry models that support smallholder livelihoods and promote sustainable land use across diverse farming landscapes.

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Author contribution DB conceived the research idea, prepared the original draft of the manuscript, and performed data curation, formal analysis, and investigation. AD prepared the original draft and performed data curation, formal analysis, and investigation. GBS and DB refined the research idea, developed the methodology, and supervised the work. UD provided additional supervision. DB carried out data collection and curation. AT contributed to the original draft preparation, data curation, and formal analysis. All authors participated in reviewing and finalizing the manuscript. DB and AD contributed equally to this work.

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Declarations

Competing interests The authors declare no competing interests.

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