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Saransh Kumar Gautam

1) Department of Silviculture and
Agroforestry, Rani Lakshmi Bai
Central Agricultural University,
Jhansi, Uttar Pradesh, India
2) Department of Silviculture and
Agroforestry, Banda University of
Agriculture and Technology,
Banda, Uttar Pradesh, India

Sanjeev Kumar

Department of Silviculture and
Agroforestry, Banda University of
Agriculture and Technology,
Banda, Uttar Pradesh, India

Corresponding Author:

Saransh Kumar Gautam

1) Department of Silviculture and
Agroforestry, Rani Lakshmi Bai
Central Agricultural University,
Jhansi, Uttar Pradesh, India
2) Department of Silviculture and
Agroforestry, Banda University of
Agriculture and Technology,
Banda, Uttar Pradesh, India

Socio-economic characteristics, landholding patterns and tree species composition in agroforestry systems of the indo-gangetic plains: A case study from Fatehpur, Uttar Pradesh, India

Saransh Kumar Gautam and Sanjeev Kumar

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Abstract

Agroforestry is a longstanding smallholder land-use strategy in the Indo-Gangetic Plains, yet socio-economic characteristics, landholding structure and tree-species functional composition have rarely been documented together for the same farming population. This study characterized agroforestry-practising households in Sultangarh and Sijoili villages, Bindki tehsil, Fatehpur district, Uttar Pradesh, India, using a structured-questionnaire survey of 100 farmers (50 per village) conducted during the 2020-21 production season, together with a farmer-reported tree-species inventory classified into Timber, Fruit and Fodder functional categories. Respondents were predominantly male (86.0%) and older (52.0% aged >55 years), with 59.0% having primary schooling or less. Marginal and small farms (<5.0 acre) accounted for 80.0% of households, and 59.0% held some leased component in their landholding. Educational attainment showed the most consistent association with landholding across the three analytical approaches, from chi-square ($\chi^2 = 27.599$, $p = 0.0063$), Kruskal-Wallis ($H = 18.81$, $p = 0.0009$) and Spearman ($\rho = 0.241$, $p = 0.0157$) analyses; the relationship between age and landholding was weak and directionally counter to a simple accumulation hypothesis, and should be interpreted cautiously given the strong collinearity between age and education ($\rho = -0.731$, $p < 0.0001$). The tree inventory comprised 21 unique tree taxa, dominated by Timber (16 of 28 farmer-reported functional-category entries, 57.1%), with 7 species (33.3%) recorded in more than one functional category, chiefly at the timber-fodder interface. These findings describe a land-constrained, mixed-tenure smallholder agroforestry system with a functionally diverse, timber-dominant tree inventory, and provide a district-level baseline for targeting agroforestry extension and tenure-related policy in this part of the central Indo-Gangetic Plains.

Keywords: Agroforestry, smallholder farmers, landholding, land tenure, tree-species composition

1. Introduction

Agroforestry - the deliberate integration of trees with crops and, in many systems, livestock - is widely regarded as a holistic approach to agricultural sustainability, combining resource-use efficiency, livelihood diversification and environmental benefit within the same land unit (Raj *et al.*, 2019) ^[11]. On-farm trees supplement staple-crop income, provide fodder and fuel, and contribute to livelihood resilience among smallholder farmers through diversified farm outputs and resource use (Debta, 2025; Palsaniya *et al.*, 2023) ^[3, 9], with homestead and farm-boundary tree systems shown to secure a more consistent household product supply and generate family-labour employment (Singh *et al.*, 2016) ^[14]. The Indo-Gangetic Plains (IGP) - spanning Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal - are a priority region for agroforestry integration, combining a dense agrarian population with extensive cereal-based cropping systems into which tree components can be incorporated (Ram *et al.*, 2022) ^[12]. Geospatial suitability mapping identifies the IGP as a high-priority zone for tree-based systems nationally (Ahmad *et al.*, 2019) ^[1], and enterprise-mix diversification incorporating trees alongside staple crops has been proposed to improve the ecological sustainability of smallholder livelihoods in the region (Yadav *et al.*, 2022) ^[17]. Evidence from eastern rural India further indicates that sustainable agricultural practices can be associated with improved multidimensional livelihood outcomes (Khosla *et al.*, 2025) ^[6]. Uttar Pradesh illustrates the diversity of agroforestry pathways within the IGP. Western

UP has undergone a marked shift toward commercial, poplar- and eucalyptus-based agroforestry since the 1990s, while central and eastern UP have retained more traditional, multi-species tree management (Verma *et al.*, 2017) ^[16]. Farmer surveys from Ballia district, eastern UP, document a predominance of scattered farm and homestead trees, with fruit, timber, shade and fodder ranked among the principal benefits (Shukla *et al.*, 2020) ^[13], and species inventories from the Vindhyan region, bordering Fatehpur, report a timber-dominated, multi-species assemblage alongside a demand-supply gap for quality timber (Srivastav *et al.*, 2024) ^[15]. Education showed the most consistent association with landholding. In a survey of 176 western-UP households, landholding size, irrigated-land area and prior tree-planting experience were positively and significantly associated with the decision to plant trees, whereas household size and education were not (Pande, 2021) ^[10]. Because farm-forestry in India is practised predominantly by small and marginal landholders raising trees on bunds and field boundaries, livelihood outcomes depend on integrating trees within, rather than displacing, existing cropping systems (Pande, 2021; Kashyap *et al.*, 2022) ^[10, 5]. Many species farmers retain are not single-purpose: UP agroforestry inventories repeatedly show a share of species serving more than one household function simultaneously, combining, for example, timber value with fruit or fodder yield (Srivastav *et al.*, 2024) ^[15]. Comparable functional diversity has been documented in an integrated agroforestry characterization from Telangana (Naveen *et al.*, 2025) ^[7] - a markedly different agro-climatic setting, but one illustrating the general pattern of multipurpose species retention by smallholders. Documenting which functions are served by which species is therefore central to understanding the practical utility of farmer-managed tree inventories, beyond a simple species list. Several studies have characterised parts of this picture elsewhere in UP, but each has addressed only a component of it for the central-UP landscape in which Fatehpur district sits. Socio-economic and land-use patterns have been documented for western UP (Verma *et al.*, 2017; Pande, 2021) ^[16, 10], Ballia district (Shukla *et al.*, 2020) ^[13] and Sonbhadra district (Anand *et al.*, 2016) ^[2]; a gender-focused survey in adjacent Sultanpur district has separately documented socio-economic decision-making patterns and a partial species list (Yashmita-Ulman & Patel, 2025) ^[18]; and tree-species composition has been documented in more detail for the Vindhyan region (Srivastav *et al.*, 2024) ^[15]. An integrated treatment combining socio-economic and species-functional data has been reported for Telangana (Naveen *et al.*, 2025) ^[7], and standardized socio-economic instruments have recently been proposed for South Gujarat (Deshmukh *et al.*, 2023) ^[4] - illustrating that integrated, statistically grounded characterization is achievable, though not yet reported for a central Uttar Pradesh, IGP setting.

The existing literature has therefore documented individual components of agroforestry systems in Uttar Pradesh - socio-economic characteristics, landholding patterns, or tree-species composition - but their integration with land-source/tenure and farmer-reported functional classification of tree species, within a single respondent-level dataset, remains limited for the central Uttar Pradesh context. The present study addresses this gap by combining, within a single dataset from two villages of Fatehpur district, (i) household socio-economic characteristics, (ii) landholding size and land-source (tenure) patterns, (iii) statistical associations between socio-economic characteristics and landholding, and (iv) a tree-species inventory classified by farmer-reported functional category (Timber, Fruit, Fodder), with explicit identification of species recorded in more than one category. The specific objectives of this study were to

characterize: (i) the socio-economic characteristics of surveyed agroforestry households in Sultangarh and Sijoili villages, Fatehpur district; (ii) landholding size and land-source (tenure) patterns among these households; (iii) statistical associations between household socio-economic characteristics and landholding; and (iv) the composition of the tree-species inventory maintained within these agroforestry systems, including the functional overlap of species recorded in more than one farmer-defined category (Timber, Fruit, Fodder).

2. Materials and Methods

2.1 Study area

The study was conducted in Sultangarh and Sijoili villages of Bindki tehsil, Fatehpur district, Uttar Pradesh, India, within the central Indo-Gangetic Plains. Fatehpur district, one of the four districts of the erstwhile Prayagraj division, occupies approximately 4,152 km² and lies in the eastern (lower) part of the Ganga-Yamuna doab, between latitude 25°26' N and longitude 80°14'-81°20' E. Among the district's three tehsils - Fatehpur, Khaga and Bindki - Bindki was selected for this investigation. The district is drained by the Ganga river system (tributaries: Yamuna, Rind); soils are predominantly Gangetic alluvium (sandy loam to clayey), and the climate is sub-humid, with mean annual rainfall of 932 mm (~90% from the south-west monsoon) and mean monthly temperatures ranging from ~8°C in January to 46.5°C in May.

2.2 Study population, sampling, variables and tree-species classification

Data were collected from farm households practising agroforestry in Sultangarh and Sijoili, two villages of Bindki tehsil. A list of farmers was compiled for each village, from which 50 respondents per village were selected using a simple random sampling procedure, giving a total sample of $n = 100$ farmers, surveyed during the 2020-21 production season through a structured questionnaire administered by personal interview. For each respondent, the questionnaire recorded gender, age, educational attainment, source(s) of land (Family, Purchased, Leased, or combinations thereof) and total landholding area (acre; 1 acre = 0.405 ha). Alongside the household survey, tree species maintained within the agroforestry systems of the two villages were recorded and consolidated into a single inventory of common and botanical names, grouped into three farmer-reported functional categories - Timber, Fruit and Fodder. Species reported under more than one category (e.g., Neem, Siris, Mahua, Subabul and Babul under Timber and Fodder; Jackfruit and Jamun under Timber and Fruit) were retained in every category reported, yielding 16 timber, 7 fruit and 5 fodder entries - 28 functional-category entries corresponding to 21 unique tree taxa overall.

2.3 Data processing and statistical analysis

Raw data were cleaned and categorical entries standardized (gender, education and land-source labels). Four variables were derived: age class (Young <35, Middle 35-55, Old >55 years); education score (ordinal, Illiterate = 0 to Graduate = 4); farm category, based on landholding (Marginal <2.5 acre, Small 2.5-5.0, Medium 5.0-10.0, Large >10.0 acre); and land source (Owned: Family/Purchased/Family+Purchased; Mixed: Family+Leased; Leased: Leased only). Data cleaning, derived-variable computation and statistical analyses were performed in Python (pandas, SciPy). Categorical variables were summarized using frequencies and percentages, while continuous variables were described using mean, median, SD, range and coefficient of variation. Associations among categorical variables were assessed using the chi-square test, monotonic relationships using

Spearman rank correlation, and differences in landholding distributions among groups using the Kruskal-Wallis H test. Statistical significance was set at $\alpha = 0.05$.

3. Results and Discussion

3.1 Socio-economic characteristics of surveyed households

Of the 100 respondents, 86.0% were male and 14.0% female (Table 1; Figure 1a), consistent with male-headed respondents predominating in comparable Ballia-district surveys (Shukla *et al.*, 2020) ^[13]. With only 14 female respondents, the non-significant gender-farm-category association ($\chi^2 = 0.735$, $df = 3$,

$p = 0.865$; Table 3, Panel A) should not be read as evidence of gender parity in land access; a gender-focused survey in adjacent Sultanpur district similarly documents pronounced male dominance in agroforestry decision-making (Yashmita-Ulman & Patel, 2025) ^[18]. The age-class distribution was skewed toward older respondents - Old (>55 years) 52.0%, Middle (35-55) 39.0%, Young (<35) only 9.0% (Table 1; Figure 1b). The predominance of older respondents is broadly comparable with observations from agroforestry households in Ballia district (Shukla *et al.*, 2020) ^[13].

Table 1: Socio-economic characteristics of surveyed agroforestry households, Sultangarh and Sijoili villages, Fatehpur district, Uttar Pradesh, India (n = 100)

Variable	Category	n (%)
Gender	Male	86 (86.0)
	Female	14 (14.0)
Age class (years)	Young (<35)	9 (9.0)
	Middle (35-55)	39 (39.0)
	Old (>55)	52 (52.0)
Education	Illiterate	27 (27.0)
	Primary	32 (32.0)
	High school	21 (21.0)
	Intermediate	15 (15.0)
	Graduate	5 (5.0)
Farm category	Marginal (<2.5 acre)	39 (39.0)
	Small (2.5-5.0 acre)	41 (41.0)
	Medium (5.0-10.0 acre)	17 (17.0)
	Large (>10.0 acre)	3 (3.0)
Land source	Family	29 (29.0)
	Leased	27 (27.0)
	Family + Leased	32 (32.0)
	Family + Purchased	10 (10.0)
	Purchased	2 (2.0)

Note: 1 acre = 0.405 ha. Percentages are column percentages of the total sample (n = 100).

Educational attainment was concentrated in the lower categories: Illiterate (27.0%) and Primary (32.0%) together accounted for 59.0% of respondents, against 21.0% High School, 15.0% Intermediate and 5.0% Graduate (Table 1; Figure 1c). This is broadly consistent with lower rural literacy levels reported for Uttar Pradesh (Verma *et al.*, 2017) ^[16]; socio-economic factors

including education and age have similarly been shown to shape agroforestry adoption in neighbouring UP districts (Anand *et al.*, 2016) ^[2]. Agroforestry was represented across all educational categories, indicating that the practice was not restricted to a particular level of formal education, as also reported for Mirzapur district, UP (Nayal *et al.*, 2024) ^[8].

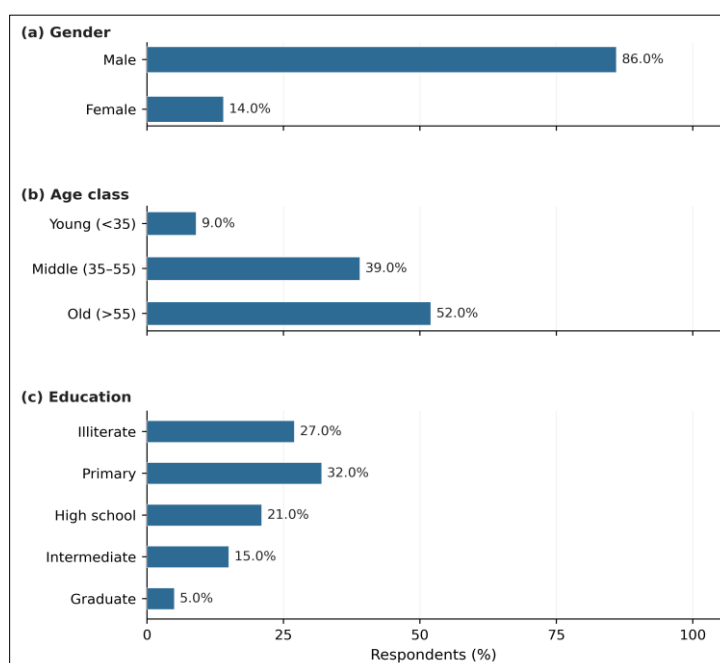


Fig 1: Socio-economic profile of surveyed households: (a) gender, (b) age class, (c) education (n = 100).

3.2 Landholding patterns and land sources

Farm-size distribution was dominated by smaller holdings: Marginal (<2.5 acre, 39.0%) and Small (2.5-5.0 acre, 41.0%) together accounted for 80.0% of households, with Medium (5.0-10.0 acre, 17.0%) and Large (>10.0 acre, 3.0%) less common (Table 1; Figure 2a), mirroring the national predominance of small and marginal holdings and the bund/boundary-planted nature of Indian farm-forestry (Pande, 2021; Kashyap *et al.*, 2022) [10, 5]. Purchased land was rare, occurring alone in 2.0% of households or in combination with family land in 10.0% (Table 1; Figure 2b).

Combining categories, 59.0% of households held some leased component. Tenure security is repeatedly identified as a determinant of tree-planting behaviour in the Indian agroforestry literature (Verma *et al.*, 2017; Pande, 2021) [16, 10]. The prevalence of mixed and leased holdings highlights the importance of considering land-tenure structure when evaluating smallholder agroforestry systems. Mean landholding increased from 1.58 acre in marginal farms to 16.53 acre in large farms, while the pooled mean was 3.68 acre (median 3.00, SD 3.01, CV 81.8%, range 0.5-19.6 acre) (Table 2)

Table 2: Landholding characteristics of agroforestry households by farm category (n = 100)

Farm category	n (%)	Mean (acre)	Median	SD	CV (%)	Range (acre)
Marginal	39 (39.0)	1.58	1.60	0.52	32.8	0.5-2.4
Small	41 (41.0)	3.56	3.40	0.75	21.0	2.5-5.0
Medium	17 (17.0)	6.54	6.00	1.30	19.9	5.2-9.6
Large	3 (3.0)	16.53	18.00	4.01	24.2	12.0-19.6
Overall	100 (100.0)	3.68	3.00	3.01	81.8	0.5-19.6

Note: Farm category thresholds as in Table 1. CV = coefficient of variation (SD/mean × 100). Overall row is the pooled sample statistic (n = 100), not a mean of the four category means. 1 acre = 0.405 ha.

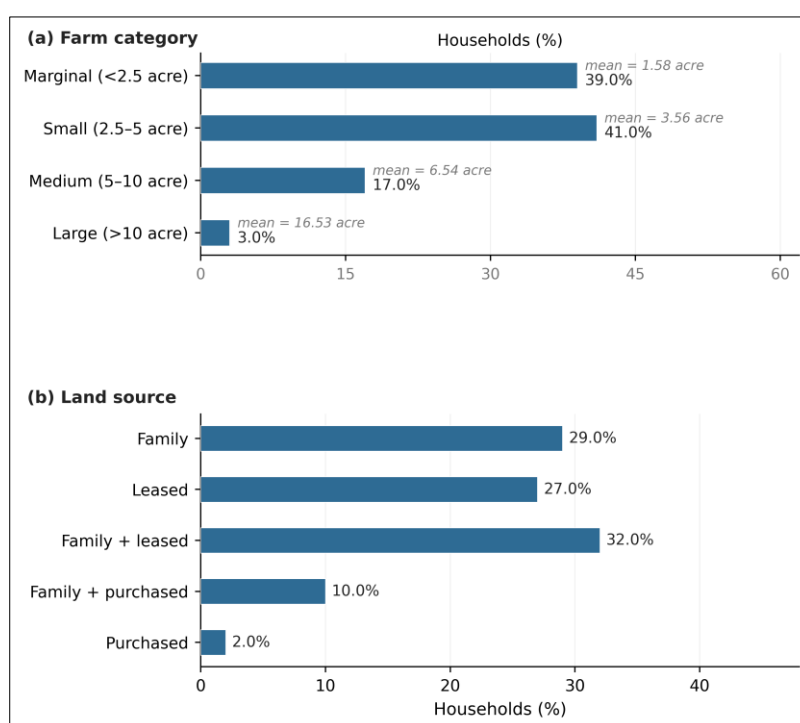


Fig 2: Landholding and land-source patterns: (a) farm category, with mean landholding per category; (b) land source (n = 100)

3.3 Relationships between socio-economic characteristics and landholding

Farm category showed an apparent association with education ($\chi^2 = 27.599$, $df = 12$, $p = 0.0063$) and age class ($\chi^2 = 16.377$, $df = 6$, $p = 0.0119$) by chi-square, though both results are indicative rather than confirmatory given that >50% of contingency-table cells had expected counts <5 (55% and 50%, respectively; Table 3, Panel A). Farm category was not significantly associated with gender ($\chi^2 = 0.735$, $df = 3$, $p = 0.865$), nor was education with land source ($\chi^2 = 22.391$, $df = 16$, $p = 0.131$; 64% of cells <5). Landholding distributions differed significantly across education groups (Kruskal-Wallis H = 18.81, $df = 4$, $p = 0.0009$) and land-source groups (H = 16.919, $df = 4$, $p = 0.0020$) but not across age-class groups (H = 5.829, $df = 2$, $p = 0.0542$) (Table 3, Panel B). Landholding was weakly and negatively correlated with age (Spearman $\rho = -0.248$, $p = 0.0128$) and weakly and positively

correlated with education score ($\rho = 0.241$, $p = 0.0157$); age and education score were themselves very strongly and negatively correlated ($\rho = -0.731$, $p < 0.0001$; Table 3, Panel C).

Table 3: Association between household socio-economic characteristics and landholding: categorical association (χ^2), landholding-distribution differences (Kruskal-Wallis H), and rank correlation (Spearman ρ)

Panel A: Categorical association (chi-square test of independence)

Variable pair	χ^2	df	P-value	Interpretation
Education × Farm category	27.599	12	0.0063	Significant *†
Age class × Farm category	16.377	6	0.0119	Significant *†
Gender × Farm category	0.735	3	0.865	ns
Education × Land source	22.391	16	0.131	ns †

Panel B: Landholding-distribution comparison across groups (Kruskal-Wallis H test)

Grouping variable	H	df	P-value	Interpretation
Education	18.81	4	0.0009	Significant *
Age class	5.829	2	0.0542	ns (borderline)
Source of land	16.919	4	0.0020	Significant *

Panel C: Rank correlation (Spearman ρ)

Variable pair	ρ	P-value	Strength & direction
Age vs. landholding	-0.248	0.0128	Weak, negative *
Education score vs. landholding	0.241	0.0157	Weak, positive *
Age vs. education score	-0.731	<0.0001	Very strong, negative *

Note: * $p < 0.05$. ns = not significant. † More than 20% of contingency-table cells had an expected count <5 (Education $\times$ Farm category, 55%; Age class $\times$ Farm category, 50%; Education $\times$ Land source, 64%); treat these results as indicative rather than confirmatory.

Education showed the most consistent association with landholding across all three approaches - a pattern reported elsewhere in Indian agroforestry contexts and attributed to mechanisms such as intergenerational transmission of education and land assets (Nayal *et al.*, 2024; Shukla *et al.*, 2020; Verma *et al.*, 2017) [8, 13, 16]. Age showed a weaker, more equivocal

relationship: because chi-square does not indicate direction, and the only directional test (Spearman) shows younger respondents holding slightly more land, the data do not support an interpretation of age-related land accumulation; the negative association therefore should not be interpreted as evidence of an age-related land-accumulation process. Because age and education are so strongly interrelated, their associations with landholding cannot be treated as independent effects from these bivariate tests.

3.4 Tree species composition and functional classification

The consolidated inventory (Table 4) recorded 21 unique tree taxa represented by 28 farmer-reported functional-category entries, comprising 16 Timber (57.1%), 7 Fruit (25.0%) and 5 Fodder (17.9%) entries (Table 5; Figure 3). The difference between the number of unique taxa and functional-category entries resulted from the classification of several taxa under more than one functional category. The timber-dominated composition was comparable with that reported from the neighbouring Vindhyan region of Uttar Pradesh (Srivastav *et al.*, 2024) [15], while differing from the more commercially specialised poplar- and eucalyptus-oriented agroforestry systems reported from western Uttar Pradesh (Verma *et al.*, 2017) [16].

Table 4: Tree species recorded in the agroforestry systems of Sultangarh and Sijoili villages, grouped by farmer-reported functional category (n = 21 unique tree taxa; 28 functional-category entries)

Functional group	Common name	Botanical name
Timber (n = 16)	Shisham	<i>Dalbergia sissoo</i>
	Teak	<i>Tectona grandis</i>
	Neem†	<i>Azadirachta indica</i>
	Siris†	<i>Albizia lebbeck</i>
	Subabul†	<i>Leucaena leucocephala</i>
	Babul†	<i>Acacia nilotica</i>
	Eucalyptus	<i>Eucalyptus spp.</i>
	Dhak	<i>Butea monosperma</i>
	Karanj	<i>Pongamia pinnata</i>
	Mahua†	<i>Madhuca longifolia</i>
	Drumstick	<i>Moringa oleifera</i>
	Jackfruit†	<i>Artocarpus heterophyllus</i>
	Jamun†	<i>Syzygium cumini</i>
	Bamboo	<i>Bambusa spp.</i>
	Arjun	<i>Terminalia arjuna</i>
	Semal	<i>Bombax ceiba</i>
Fruit (n = 7)	Mango	<i>Mangifera indica</i>
	Amrud (Guava)	<i>Psidium guajava</i>
	Jackfruit†	<i>Artocarpus heterophyllus</i>
	Aonla	<i>Phyllanthus emblica</i>
	Bel	<i>Aegle marmelos</i>
	Jamun†	<i>Syzygium cumini</i>
Fodder (n = 5)	Ber	<i>Ziziphus spp.</i>
	Subabul†	<i>Leucaena leucocephala</i>
	Babul†	<i>Acacia nilotica</i>
	Neem†	<i>Azadirachta indica</i>
	Siris†	<i>Albizia lebbeck</i>
	Mahua†	<i>Madhuca longifolia</i>

Note: † Recorded in more than one functional category: all 5 fodder species are also timber species, and 2 timber species (Jackfruit, Jamun) are also fruit species - 7 of 28 entries cross-listed, giving 21 unique tree taxa overall (Table 6). Ber, Eucalyptus and Bamboo are recorded to genus level only, reflecting the resolution of the original field inventory.

The presence of a diverse fruit component, including mango, guava, aonla, bel and ber, also indicates the incorporation of tree-based products beyond timber, consistent with the multifunctional nature of agroforestry systems documented in Uttar Pradesh (Shukla *et al.*, 2020) [13]. A notable feature of the inventory was the multifunctionality of several tree taxa. Seven of the 21 unique taxa (33.3%) were reported under more than one functional

category (Table 6). The largest overlap occurred between Timber and Fodder, with all five fodder taxa—Subabul, Babul, Neem, Siris and Mahua—also classified as Timber. This pattern indicates the importance of multipurpose tree classification in smallholder agroforestry, where individual taxa may be associated with more than one farmer-reported function (Srivastav *et al.*, 2024) [15].

Table 5: Functional composition of the tree-species inventory recorded in the study area

Functional group	No. of entries	% of 28-entry pool
Timber	16	57.1
Fruit	7	25.0
Fodder	5	17.9
Total	28	100.0

Note: Entries refer to farmer-reported functional-category entries, not unique species.

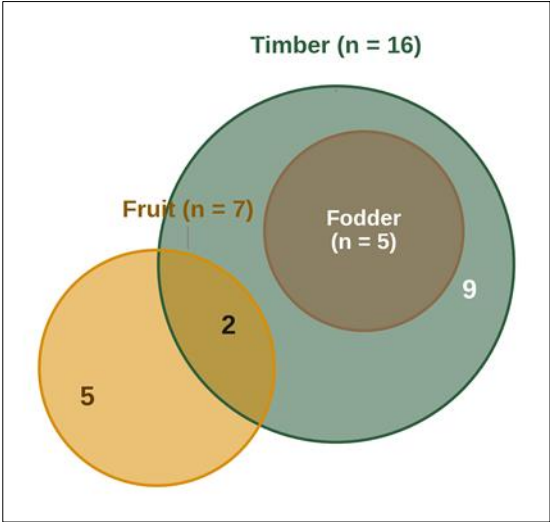


Fig 3: Functional overlap of farmer-reported tree species categories: 16 Timber, 7 Fruit and 5 Fodder farmer-reported entries and their overlap

A smaller Timber-Fruit overlap was observed for Jackfruit and Jamun. No taxon was reported simultaneously under all three categories, and no direct overlap occurred between Fruit and Fodder. Thus, functional overlap was concentrated primarily at the Timber-Fodder interface, followed by the Timber-Fruit interface, indicating that farmer-reported tree composition was characterised by a combination of timber-oriented and multipurpose tree resources rather than by strictly single-purpose species groups.

Table 6: Cross-listed (multipurpose) tree species and their farmer-reported functional-role membership

Species	Botanical name	Timber	Fruit	Fodder
Subabul	<i>Leucaena leucocephala</i>	✓	-	✓
Babul	<i>Acacia nilotica</i>	✓	-	✓
Neem	<i>Azadirachta indica</i>	✓	-	✓
Siris	<i>Albizia lebbeck</i>	✓	-	✓
Mahua	<i>Madhuca longifolia</i>	✓	-	✓
Jackfruit	<i>Artocarpus heterophyllus</i>	✓	✓	-
Jamun	<i>Syzygium cumini</i>	✓	✓	-

Note: ✓ = functional role reported by respondents. All 7 rows are the complete set of cross-listed species; the remaining 14 of 21 species were recorded in exactly one category.

4. Conclusion

This study characterized agroforestry-practicing households in two villages of Fatehpur district, Uttar Pradesh, integrating socio-economic profiles, landholding and tenure patterns, and tree-species functional composition within a single dataset. Surveyed households were predominantly marginal and small farmers (80.0% of the sample) operating under tenure that was frequently mixed or leased (59.0% with some leased component). Educational attainment was the socio-economic characteristic

most consistently associated with landholding across chi-square, Kruskal-Wallis and Spearman analyses, whereas age showed only a weak, negative association with landholding that should be interpreted cautiously given the strong collinearity between age and education in this sample. The tree-species inventory comprised 21 unique tree taxa dominated by Timber (16 of 28 functional-category entries, 57.1%), with Fruit (25.0%) and Fodder (17.9%) also represented; seven species (33.3%) served more than one functional role, chiefly at the timber-fodder interface. These findings describe a land-constrained, mixed-tenure smallholder agroforestry system with a functionally diverse, timber-dominant tree inventory. Agroforestry extension programmes in this landscape should account for the predominance of small and mixed-tenure holdings and the relatively low educational attainment of many practitioners. Extending this integrated characterization across additional central Uttar Pradesh districts would help establish how representative this pattern is of the broader Indo-Gangetic Plains.

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