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Beyond Market Value: Multiple Uses, Uneven Monetization, and Governance Barriers for Associated Trees in Côte d'Ivoire's Cocoa Agroforestry Systems

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Beyond Market Value: Multiple Uses, Uneven Monetization, and Governance Barriers for Associated Trees in Côte d'Ivoire's Cocoa Agroforestry Systems

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Abstract

Beyond their well-documented agronomic role in cocoa yield, trees associated with cocoa farms in Côte d'Ivoire fulfil direct-use functions (food, shade, timber, medicinal, boundary-marking, belief) whose extent and monetization remain poorly documented at the national scale. We analyse 3403 species×site records (452 farms, three production loops, 387 species), coding the declared function(s) of each species and its reported economic value, classified into six mutually exclusive categories (no value, self-consumption, sale with an annual amount, sale at a unit price, sale with an unspecified amount, not interpretable), rather than a single income figure, owing to the heterogeneity of the reported formats. The food function dominates by far (59.2% of records), followed by shade (20.0%) and timber (12.6%). A value (monetary or self-consumption) is reported for only 23.5% of records (14.8% with an exploitable annual sale amount, median 10000 FCFA), with a marked contrast between loops (8.1% to 29.6%, $p<0.0001$). A species-function bipartite network shows that a restricted core of fruit-tree species accounts for most of the recorded uses; iroko stands out with the most diversified functional portfolio (8 of 8 functions). A complementary farm-level analysis ($n=452$) shows that 11.3% of farmers report a difficulty exploiting forest trees, 78.3% of which involve a conflict with a third party (a private logger or the Water and Forests administration) rather than a market constraint; which sheds light on the near-absence of timber monetization. Cross-referencing the species farmers prefer and those they would like to remove with their measured functional profile reveals that preference reflects, depending on the species, use diversity (iroko), market value (akpi), or an acknowledged ambivalence (fromager, both preferred and, most often, a candidate for removal). These results indicate that the socio-economic value of trees associated with cocoa farms in Côte d'Ivoire owes less to a generalized monetary flow than to a direct-use service (food first and foremost) whose monetization remains partial, geographically uneven, concentrated on a restricted core of species, and constrained in part by governance barriers rather than by commercial demand alone.

Keywords: Socio-economic value associated trees, non-timber forest products, species-use network, Côte d'Ivoire, cocoa agroforestry

Introduction

Beyond their agronomic contribution to cocoa yield, well established for the planted origin of associated trees in the regional agroforestry literature (Konan et al., 2025), trees associated with cocoa farms fulfil, in most West African agroforestry systems, direct-use functions for the farmer: shade, timber, food, traditional medicine, plot boundary-marking, or cultural and spiritual value. Some of these uses translate into a monetary value, while others amount to self-consumption or non-market services. Farmers' decisions to keep, plant, or remove an associated tree depend strongly on how they perceive its overall use value (economic motivations, but also identity-related and cultural ones Dago et al., 2025)) and this value, historically documented at the scale of the household and its market or subsistence needs (Sonwa et al., 2014), remains rarely quantified at the national scale from systematic survey data rather than localized case studies.

In Côte d'Ivoire, an emerging body of literature links the ecosystem services provided by cocoa agroforestry systems (of which the use value of associated trees is one component) to farmers' living income (Tokou et al., 2026), without documenting in detail the structure of the functions and monetization of the associated trees themselves across the three historical cocoa-growing zones. The source thesis for this work (Adji et al., 2016) recorded, for 452 farms covering these three zones, the declared function(s) of each associated tree species, the plant part, if any, harvested or sold, and a declared income or quantity (a field never exploited until now, not least because its raw format is considerably more heterogeneous than that of the survey's other variables). A distinct but related question also deserves to be asked: *what barriers do farmers themselves identify to exploiting these trees, and do their declared preferences match the use value actually measured*? Recent literature on tree tenure in West Africa documents that uncertainty over ownership rights to high-value trees discourages their conservation and valuation by farmers, independently of commercial demand (Kouassi et al., 2021; O'Sullivan et al., 2021; USAID ILRG, 2021). The source thesis also collected, for the same 452 farms, the declared difficulties exploiting forest trees, the solutions proposed, and the species farmers prefer and those they would like to remove (fields never exploited until now).

Methodologically, quantifying the declared uses of a community of woody species follows the tradition of quantitative ethnobotany (Phillips and Gentry, 1993a, 1993b; Tardío and Pardo-de-Santayana, 2008), which chooses not to reduce the value of a taxon to a single function. A recent study of the ethnoecology of *Canarium schweinfurthii* in Cameroon illustrates this approach by combining use frequencies with plant part-use flow diagrams (Chakocha et al., 2025). a visualization structure that we adapt in this paper to the scale of Côte d'Ivoire as a whole rather than a single site.

This article addresses four research questions, each paired with a hypothesis motivated by the literature above:

- ✓ Q1: How are the declared functions of associated trees structured, and do they vary across the three main production « loops »?
- ✓ H1: the food function dominates the sample but declines in favour of structural functions (shade, timber) in the older production zones, consistent with the idea that the balance between market and household needs shapes the functional composition of cocoa agroforestry systems (Sonwa et al., 2014) ;
- ✓ Q2: What is the extent and structure of the economic valuation of these trees?
- ✓ H2: this monetization is partial and concentrated on a small core of fruit-tree species, by analogy with the concentration of use value already observed in other plant communities (Phillips and Gentry, 1993b) ;
- ✓ Q3: Is the underlying species-function network dominated by a versatile core of species, or is use value spread more evenly across the recorded species assemblage?
- ✓ H3: a small number of multifunctional species accounts for most of the declared functions, consistent with the role of multiple use value in farmers' decisions to keep a tree (Dago et al., 2025) ;
- ✓ Q4: What barriers do farmers themselves identify to exploiting these trees, and do their declared preferences match the measured use value of the species?
- ✓ H4: these barriers stem more from tenure conflicts with third parties than from commercial constraints, consistent with the literature on tree governance in West Africa (Kouassi et al., 2021; O'Sullivan et al., 2021).

Materials and Methods

Study area and survey sites

The data used here come from the field survey described in a Master's thesis in agroforestry from Jean Lorougnon Guédé University in Côte d'Ivoire (Adji et al., 2016). This survey, conducted using field questionnaires (Supplementary material: S2), covered 474 cocoa farms (452 of which have usable data for the present study) spread across 16 departments or sub-prefectures and 103 villages or hamlets, grouped into three major Ivorian cocoa-growing production zones (« loops »): Loop 1 (East/South-East, 4 departments, 28 sites), Loop 2 (Centre/Centre-West, 8 departments, 51 sites) and Loop 3 (South/South-West, 4 departments, 24 sites) (Figure 1, Table 1). This national coverage distinguishes this study from ethnobotanical work generally conducted at the scale of a single site or ethnic group (see for example Chakocha et al., 2025).

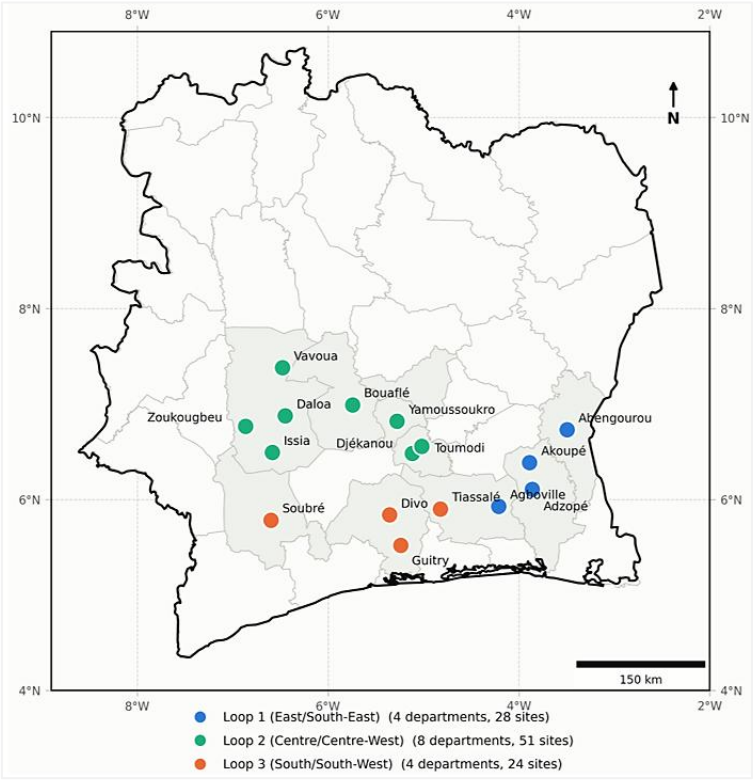


Fig. 1. Location of the 16 survey departments (coloured by production loop), grouping the 103 recorded survey sites (villages and hamlets; see Table 1).

Table 1. Survey sites by cocoa-growing loop (16 departments/sub-prefectures, 103 villages and hamlets).

Cocoa-growing zones	Regions	Departments	Survey sites (sub-prefecture, villages and hamlets)
Loop 1 (East/South-East)	Indénié-djuablin	Abengourou	Akoikro (N'zebenou), Amelekia, Arifi, Kodjinan, Kouassibeniekro, Niable (Adoninkro, Affalikro, Assokro, Anuanuan, Anuansuê), Yakassé Feyassé (Eboissue, Sankadiokro), Konankro.
	Mé	Adzopé	Agou (N'guessankoi), Ahuikoi, Biasso, Nehanzin.
		Akoupé	N'koupé.
	Agneby-tiassa	Agboville	Petit Yapo, Grand Morié, Grand Yapo, Offa, Grand Yapo, Boka Oho, Offoumpo.
Total	3	4	28
Loop 2	Belier	Djekanou	Albertn'dakro, Djetran-Yaokro, Kocoubo, Mougnan, Wobekro.
		Toumodi	Assouvoue, Bofledo, Lahourebo, N'doukahakro.
		Daloa	Bohoua-Bahouan, Bohouahawa, Carrefou Pk 12, Gboguhé (Keibla), M'bayakoffikro, Tapeguhé.
		Vavoua	Vavoua, Bonoufla.

(Centre/Centre-West)	Haut Sassandra	Issia	Boguédia (Mimia1, Mimia2, Mimia3), Issia, Iboguhé, Madrassokouro, Mandiassoucloi, Tetia.
		Zoukougbeu	Gregbeu (Blaikro), Guessabo (Ouatigbeu, Gorodi, Dagbrezou).
	Lac	Yamoussoukro	Kossou (Angosse, Yobouekro), Senan.
	Marahoué	Bouaflé	Benou, Bledi, Bonon (Djahakro, Saa, N'guessankro, Bokrolaye), Bozy, Garango, Koupela, Lopouafla, Pakouafla, Pakouabo, Sokrolaye, Tingodogo.
Total	4	8	51
Loop 3 (South/South-West)	Lôh-Djiboua	Divo	Bradodougou, Konankro, Pétimpé, Yobouékro, Boubo, Data, Tablédjou, Didoko, Hiré, Hiré (Boakako, Kagbé), Ogoudou (Kouamékro).
		Guitry	Warkro
	Nawa	Soubré	Alloukro, Kouadiokro, Négréagui, Oupoyo, Campement Loua-paul, Norbert Carrefour.
	Agneby-Tiassa	Tiassalé	Sokorogbo, Eticoon, Gnangnankansou, Dibykro, N'douci (Abéré).
Total	3	4	24

Data source and quality

The data come from the « Associated Species Census » sheet of the field survey dataset (Adji et al., 2016) ; "RECENSEMENT DES ESPECES ASSOCIE" in the raw dataset), after location cleaning (3403 species×site records across the 452 farms covering the three loops). Each record corresponds to a species declared at a given locality, with its number of stems, its origin (remnant/spontaneous/planted), its declared function(s), the plant part, if any, harvested, and an annual income or harvested quantity field (see the attached survey form and the « data availability » section). The recording resolution of this sheet is, however, very uneven across zones: only 3 distinct localities are recorded in the East/South-East loop, versus 88 in the Centre/Centre-West loop and 28 in the South/South-West loop, owing to department-level aggregated recording in the East/South-East loop. Comparisons between loops reported in this article should therefore be interpreted with caution for this zone, whose 852 records come from a very small number of independent survey points. Two pairs of vernacular names corresponding to the same data-entry error (« citronier »/ « citronnier »; « oranger »/ « orangier ») were merged before any species-level analysis; the 387 distinct vernacular names reported below reflect this correction.

Decoding functions and harvested plant parts

The « function » and « harvested plant part » fields (named « role » and « organe-util » in the raw dataset) use a multiple-code convention (codes separated by a period or comma, with parenthetical annotations to be stripped). The questionnaire codebook defines eight functions (1=Shade, 2=Fertilization, 3=Food, 4=Timber, 5=Boundary marking, 6=Medicinal, 7=Belief, 8=Other) and six plant parts (1=Leaves, 2=Fruit, 3=Bark, 4=Roots, 5=Sap, 6=Other; 0=none). A peculiarity specific to this sheet was identified through an exhaustive inspection of every distinct value of the « function » field before decoding: a small number of responses (39 of 3403 records) are two-digit numbers with no separator (for example « 13 », « 14 », « 61 »), which cannot correspond to a single valid code (the codebook stops at 8) and were therefore decoded digit by digit (« 13 » → codes 1 and 3). The « harvested plant part » field, more marginally (12 records), contains codes 7 to 9 that are not defined in the documented codebook; these were kept as such in an "uncoded" category rather than being arbitrarily reinterpreted.

Classification of the economic valuation

The « declared annual income » and « quantity » fields (named « revenu/an » and « quantité » in the raw dataset) proved, after exhaustive inspection of their 183 and more than 150 distinct text values respectively, considerably more heterogeneous than any other field decoded for this study: raw numeric amounts, annotated amounts (« 5000fcfa/an », « 20000fcfa »), self-consumption statements (« propre consommation », « auto conso »), unit prices (« 250fcfa/kg », « 1kg à 300fcfa »), physical quantities that had apparently migrated from the quantity column to the income column or vice versa (« 3sacs/pied », « 5 sacs »), sale statements with no amount

(« vente »), and a residue of non-numeric or evidently misplaced responses (two responses, « médicinale » and « fertilisation », clearly correspond to function labels entered by mistake in the income field). Rather than forcing all of these responses into a single annual-income figure (which would have mixed non-comparable scales and units (unit price versus total annual amount)), each record was classified into one of the following six mutually exclusive categories, combining information from both fields: no value declared; self-consumption (explicit non-market use); sale with an annual amount (a figure interpretable as an annual total in FCFA); sale at a unit price (a figure interpretable as a price per kg, litre, sack, or unit, not directly comparable to an annual total); sale with an unspecified amount (mention of a sale with no associated figure); not interpretable (residual text with no usable quantitative or categorical information, 1.2% of records).

This classification, fully documented in the data-preparation script, favours transparency over false precision.

Declared barriers, proposed solutions, and species preferences (farm-level complementary analysis)

Beyond the fields already used above, the « General Information on Cocoa and Trees » sheet (« INFO GENERALES SUR CACAO ET ARB » in the raw dataset) includes four fields never exploited until now, although explicitly identified as relevant to a paper on the socio-economic value of associated trees from the initial data audit onward: the declared difficulties exploiting forest trees (with identification of the party responsible), the solutions proposed by the farmer, and the forest species the farmer prefers or would like to remove. These four fields are used here in a complementary analysis, at the farm scale (n=452, General Information sheet) rather than the species×site scale (n=3403, Associated Species Census sheet) used throughout the rest of this article: since the two sheets share no common farm identifier, it is not possible to link a given species×site record to an individual farm's answer on these four fields. This complementary analysis nonetheless provides a direct, national-scale perspective on the possible causes of the low monetization observed for certain functions (timber in particular), and on the consistency between farmers' declared preferences and the species' actually measured use value.

The declared-difficulties field, coded 1 (yes, with a free-text annotation of the identified responsible third party) or 2 (no), was decoded into thematic categories through an exhaustive inspection of the annotations: conflict with a logger, conflict with the Water and Forests administration (the state forestry authority), damage linked to logging (felling, removal), conflict with a charcoal producer, or unspecified difficulty. Three responses coded « 0 » and one aberrant response (a species name evidently misplaced in this field) were excluded as not interpretable, in the same way as the aberrant values already encountered and documented for the « declared annual income » field. The proposed-solutions field, in free text, was classified into six mutually exclusive thematic categories (land/tree ownership rights, prior consultation/consent, regulatory reform, fair compensation and transparency, state support or technical guidance, halting industrial logging), fully documented in the analysis script. The preference and removal fields, in free text with multiple comma-separated answers, were broken down species by species and then cross-referenced with each species' already computed functional and valuation profile.

A complementary sheet in the source thesis includes a « tree species encountered » field per farm, identified as the variable needed to link a farm's associated-species richness to its declared difficulties and preferences. A rigorous row-by-row alignment audit (verified through chained exact matches on several independent shared fields (declared preference and removal, at 100% and 99.8% agreement respectively), not through a mere assumption of positional order) confirms that this sheet is reliably linked to the 452 farms in the « General Information on Cocoa and Trees » sheet already used throughout the rest of this complementary analysis. Associated-species richness per farm could therefore be computed as the number of distinct species listed in this field (452/452 farms with data), and tested against declared difficulties and preferences.

Ethical framework of the study

The source field survey (Adji et al., 2016) was conducted as part of a university Master's thesis, with voluntary participation of the farmers interviewed and anonymization of farms from the point of collection onward (identifiers PL-001 to PL-451; no nominative data is retained in the dataset used here). No sensitive personal data, no species classified as threatened under international conservation lists, and no protected cultural or ceremonial

site was identified or precisely located in the data used for this article. This study was not subject to a formal institutional ethics committee review, a step that was not systematically required for Master's theses at the originating institution at the time of data collection (2015-2016-2017); the authors recommend that such a review be sought for any future extension of this work involving new data collection from farmers.

Data analysis

All statistical analyses and the construction of the species-function bipartite network were carried out in Python (pandas, scipy, statsmodels, networkx). The statistical significance threshold is set at 0.05 for all tests reported.

The structure of declared functions is summarized, for each function *f*, by its relative frequency within the sample:

$$Fc_f = (n_f / N) \times 100$$

where n_f is the number of records reporting function *f* and *N* the total number of records; a measure directly analogous to that used in comparable quantitative ethnobotanical studies (Chakocha et al., 2025; Phillips and Gentry, 1993a; Tardío and Pardo-de-Santayana, 2008).

Four statistical tests, all classic ones, are also used throughout this paper for between-group comparisons.

- ✓ Independence between a categorical variable (function, valuation category) and the production loop is tested with Pearson's chi-square test of independence (Pearson, 1992) :

$$\chi^2 = \Sigma\, (O_i - E_i)^2 / E_i$$

where O_i is the observed count and E_i the expected count under independence in each cell *i* of the contingency table (function or category × loop).

- ✓ The comparison of the annual sale amount and of associated-species richness across the three loops, non-normally distributed continuous variables, uses the non-parametric Kruskal-Wallis test (Kruskal and Wallis, 1952) :

$$H = [12 / (N(N+1))] \times \Sigma\, (R_k^2 / n_k) - 3(N+1)$$

where *N* is the total sample size, n_k the size of group *k* (a loop), and R_k the sum of ranks of group *k* in the combined ranking of the three loops.

- ✓ The comparison of associated-species richness between farms with and without a declared difficulty, two independent groups, uses the non-parametric Mann-Whitney test (Mann and Whitney, 1947), built on the same rank logic but for two groups only:

$$U = n_1 n_2 + [n_1(n_1+1)/2] - R_1$$

where n_1 and n_2 are the sizes of the two groups compared and R_1 the sum of ranks of the first group.

- ✓ Finally, the association between associated-species richness per farm and the number of species cited as preferred or as candidates for removal is measured with Spearman's rank correlation coefficient (Spearman, 1904) :

$$\rho = 1 - [6\, \Sigma\, d_i^2 / (n(n^2-1))]$$

where d_i is the rank difference between the two variables for farm *i* and *n* the number of farms compared.

Results

Sample overview

The sample comprises 3403 species×site records (852 in the East/South-East loop, 1240 in the Centre/Centre-West loop, 1311 in the South/South-West loop), representing 387 distinct common species and a total of 25090 recorded stems. The four most frequently recorded species are the avocado tree (376 records), the

mango tree (351), the orange tree (312) and the oil palm (300), all four fruit-tree species. Table 2 presents the distribution of declared functions of all recorded species, for the overall sample and by production loop.

Table 2. Distribution of declared functions of associated trees, overall sample (*n*=3403) and by production loop (%).

Function	Overall (%)	Loop 1 (%)	Loop 2 (%)	Loop 3 (%)	*Chi² (p)*
Food	59.2	38.8	62.7	69.0	*<0.0001*
Shade	20.0	27.5	25.6	9.9	*<0.0001*
Timber	12.6	25.1	9.4	7.5	*<0.0001*
Other	12.6	6.3	23.8	6.2	*<0.0001*
Medicinal	8.6	3.6	8.6	11.8	*<0.0001*
Fertilization	3.3	2.7	4.4	2.7	*0.023*
Boundary marking	1.7	0.0	1.0	3.4	*<0.0001*
Belief	0.2	0.0	0.0	0.5	*0.008*
No function declared	10.4	14.4	10.6	7.5	-

Categories are not mutually exclusive (a species can serve several functions). *Chi²*: function × loop independence test.

Functions and harvested plant parts, geographic variation

The food function dominates the sample by a wide margin (59.2%), but with a clear gradient across zones: from 38.8% in the East/South-East loop to 69.0% in the South/South-West loop. This gradient is roughly reversed for shade (27.5% in Loop 1 versus 9.9% in Loop 3) and timber (25.1% versus 7.5%), suggesting that the associated trees recorded in the East/South-East loop fulfil a more structural function (shade, timber) and a less directly food-related one than in the other two zones (Figure 2). The "Other" category (12.6% on average) is strongly concentrated in the Centre/Centre-West loop (23.8%); closer examination shows that it is carried, in 83% of cases (357/430), by the same dominant fruit-tree species already classed under the food function (avocado, orange, oil palm, mango trees), and that 155 of the 430 "Other" records also report a sale with an annual amount; suggesting that this category largely captures a commercial function declared separately from the food function rather than a truly distinct use.

The most frequently harvested plant part is the fruit (56.1% of records), well ahead of leaves (10.2%), bark (6.0%), sap (5.5%) and roots (2.2%); no plant part is recorded for 30.3% of records, a proportion consistent with that of species with a structural function (shade, timber) for which harvesting a plant part is not relevant. The prevalence of each plant part also varies significantly by loop (chi-square $p<0.05$ for all six plant parts), with the same Loop 1-to-Loop 3 gradient observed for the food function (fruit: 38.5% in Loop 1 versus 66.3% in Loop 3).

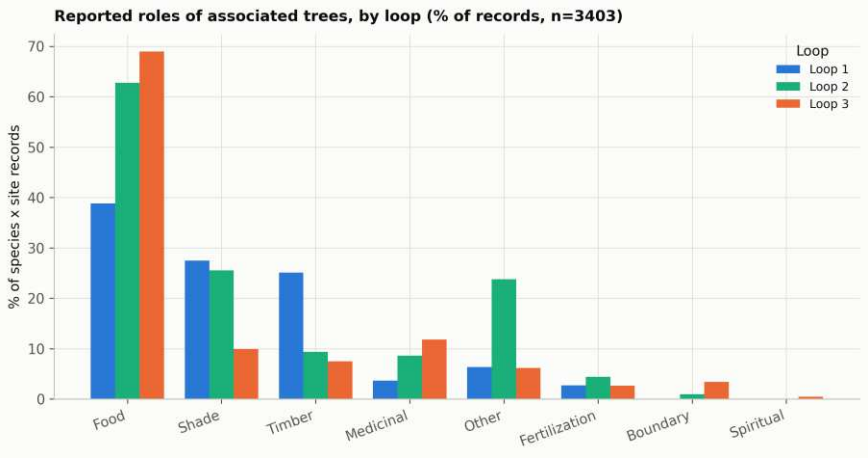


Fig. 2. Declared functions of associated trees, by production loop (% of species×site records, *n*=3403).

Beyond prevalence by function alone (Figure 2), the combination of the eight declared functions draws a differentiated use profile by loop, visible on a radar chart (Figure 3). The food function dominates the common radial scale so strongly (from 38.8% to 69.0% depending on the loop, against a maximum of 27.5% for any other

function) that it visually compresses the other seven functions near the centre of the chart; a complementary version excluding the food function alone (Supplementary Figure S1) thus more clearly reveals the secondary differentiation between loops already described above: the East/South-East loop stands out for timber, the Centre/Centre-West loop for the « Other » category and for shade (the highest of the three loops), and the South/South-West loop for the medicinal function.

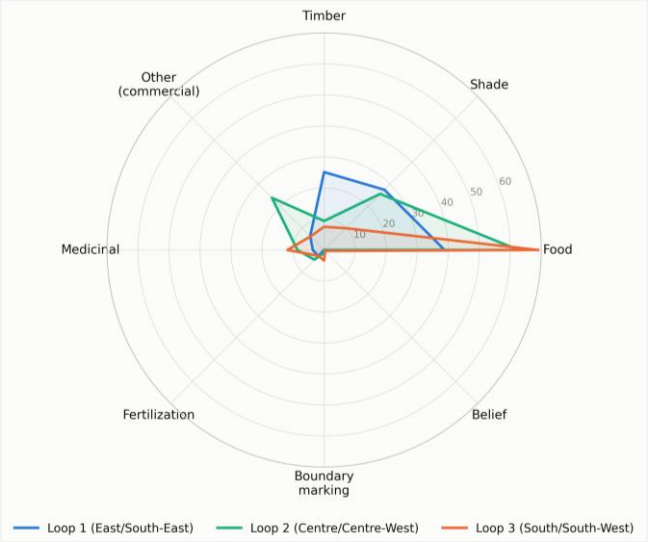


Fig. 3. Declared use categories of associated trees, by production loop (radar chart; % of species×site records within each loop, *n*=3403; categories not mutually exclusive). See Figure S1 for a secondary-use-only version excluding the dominant Food category.

Classification of the economic valuation

A value (monetary or self-consumption) is reported for 801 of the 3403 records (23.5%); the remaining 76.5% are split between no value declared (75.3%) and not-interpretable responses (1.2%). Among records with a value, sale with an exploitable annual amount is the most frequent category (502 records, 14.8% of the total sample), followed by self-consumption (232, 6.8%), sale at a unit price (58, 1.7%), and sale with an unspecified amount (9, 0.3%). Table 3 presents this breakdown for the overall sample and by production loop.

Table 3. Classification of the economic valuation of associated trees, overall sample and by production loop (%).

Category	Overall (%)	Loop 1 (%)	Loop 2 (%)	Loop 3 (%)	*Chi² (p)*
No value declared	75.3	91.9	70.2	69.2	*<0.0001*
Sale, annual amount	14.8	5.9	18.1	17.4	*<0.0001*
Self-consumption	6.8	1.2	8.4	9.0	*<0.0001*
Sale, unit price	1.7	1.1	1.3	2.5	*0.014*
Sale, amount unspecified	0.3	0.0	0.0	0.7	*0. 0007*†
Not interpretable	1.2	0.0	2.0	1.2	*0.0002*

n = 3403. *Chi² (p)*: chi-square test of independence between each valorisation category (presence/absence) and loop (2 df per test). Omnibus test across all 6 categories: $\chi^2 = 196.21$, $df = 10$, $p < 0.0001$. † Expected cell counts are low for this category (9 records overall); confirmed with Fisher's exact test ($p = 0.0008$)

Determinants of the sale amount and species ranking

The share of records with any value reported varies very sharply by loop: 8.1% in the East/South-East loop, versus 27.7% in the Centre/Centre-West loop and 29.6% in the South/South-West loop (overall *Chi²* $p<0.0001$). This contrast may reflect a real difference in the economic valuation of associated trees between zones, but also, at least in part, the more aggregated recording resolution already noted for the East/South-East loop (3 localities versus 88 and 28); a limitation that prevents a definitive choice between these two explanations from the available data alone.

The annual sale amount (n=502, median 10000 FCFA, mean 22030 FCFA, range 1-300000 FCFA) differs significantly by loop (Kruskal-Wallis test, H=33.52, p<0.0001): the highest median is in the Centre/Centre-West loop (12000 FCFA, n=224), versus 4000 FCFA in the East/South-East loop (n=50) and 5000 FCFA in the South/South-West loop (n=228) (Figure 4, panel B). Valuation also varies strongly with the species' declared function: among records with a food function, 36.7% report any value (23.0% sale with an annual amount, 11.1% self-consumption), versus only 2.6% for timber; suggesting that timber harvested from associated trees is mostly used domestically (construction, firewood) in a way not captured by the questionnaire's income field, rather than reflecting a real absence of value.

Ranking species by median sale amount (among those with at least 5 recorded sales) places the oil palm first (median 30000 FCFA, n=66), followed by akpi (median 20000 FCFA, n=11) and the orange tree (median 10000 FCFA, n=111); the avocado tree, although the most frequently recorded species, ranks in the middle of the table, tied with the kola tree (median 8000 FCFA, n=133 and n=23 respectively), while the guava tree comes last (median 758 FCFA, n=10); a ranking that clearly separates a species' citation frequency from its unit market value.

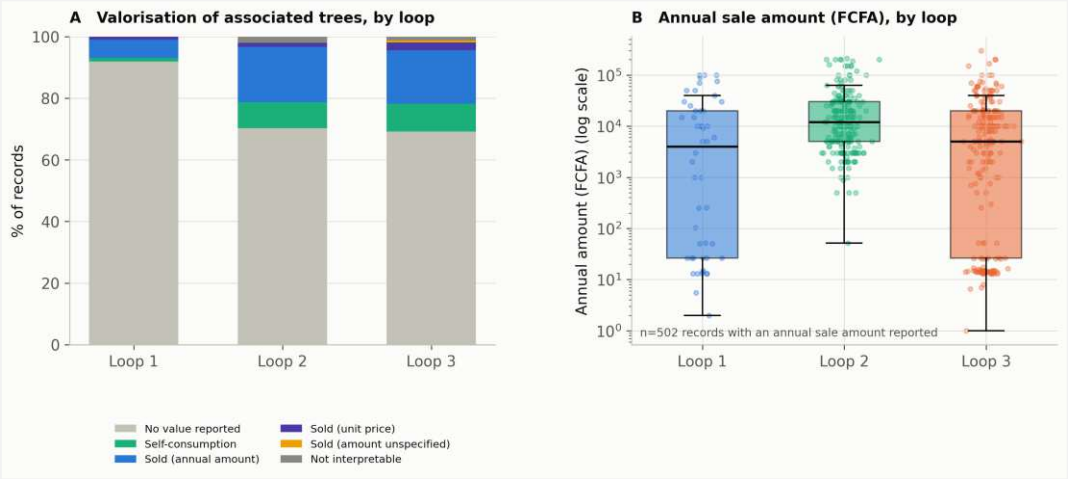


Fig. 4. (A) Classification of the economic valuation of associated trees, by loop (% of records). (B) Annual sale amount (FCFA, log scale), by loop, among the 502 records with an exploitable amount (Kruskal-Wallis test, H=33.52, p<0.0001).

The preceding analyses compare loop and declared function separately; a logistic regression model makes it possible to check whether the geographic effect persists once each record's functional composition is taken into account. The model predicts the probability that a species×site record reports any value (monetary or self-consumption) from the production loop and the eight declared functions (non-exclusive binary variables), with the East/South-East loop and the absence of each function as reference categories (n=3403, McFadden's pseudo-R^2=0.203). The belief function had to be excluded from the model: none of the 6 records concerned report a value, which produces perfect separation and prevents convergence of the maximum-likelihood estimate for this term; a minor limitation given the very small size of this function (3 of 50 species in the Figure 6 network). Once functional composition is controlled for, the effect of the production loop remains clear and significant: an odds ratio (OR) of 2.61 for the Centre/Centre-West loop and 3.57 for the South/South-West loop relative to the East/South-East loop (p<0.001 in both cases), confirming that the geographic contrast documented above is not explained solely by a different functional composition from one zone to another. Among functions, the food function is by far the strongest predictor (OR=14.10, p<0.001), followed by shade (OR=1.64, p<0.001); timber, conversely, significantly reduces the probability of a reported value (OR=0.52, p=0.047), statistically confirming the marked under-monetization of this function already noted above. The medicinal, fertilization, and boundary-marking functions do not emerge as significant predictors once the other factors are taken into account (Figure 5).

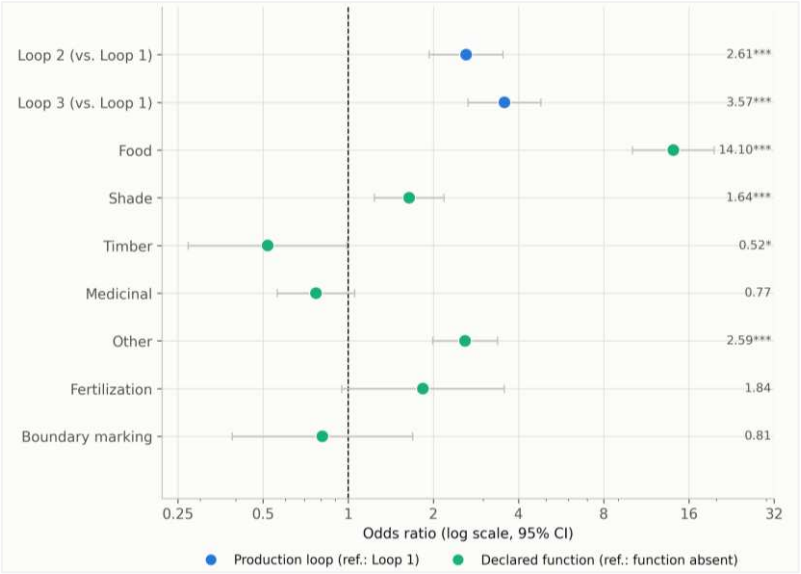


Fig. 5. Determinants of reporting any economic value (logistic regression, n=3403 species×site records): odds ratios and 95% confidence intervals for production loop (reference: Loop 1, East/South-East) and declared function (reference: function absent). role_croyance excluded (perfect separation, 0/6 records with value reported). * p<0.05, ** p<0.01, *** p<0.001.

Species-function bipartite network

The species-function bipartite network, restricted to the 50 species recorded at least 5 times (out of 387 in total), shows a structure clearly centred on a small core of generalist fruit-tree species. Iroko has the most diversified functional portfolio (8 distinct functions out of the 8 possible, for 111 records), followed by the mango tree, the oil palm, fromager, frake, and the guava tree (7 functions each); a versatility consistent with iroko's well-documented status as a multi-use species in West Africa (timber, shade, traditional pharmacopoeia, and ceremonial use: it is the only species, along with the guava tree and, anecdotally, the lemon tree, associated with the belief function in this sample). On the function side, shade is the most generalist (48 of the 50 species retained), followed by the medicinal function (33 species) and timber (34 species), while belief (3 species) and fertilization/boundary-marking (20 species each) remain niche functions (Figure 6).

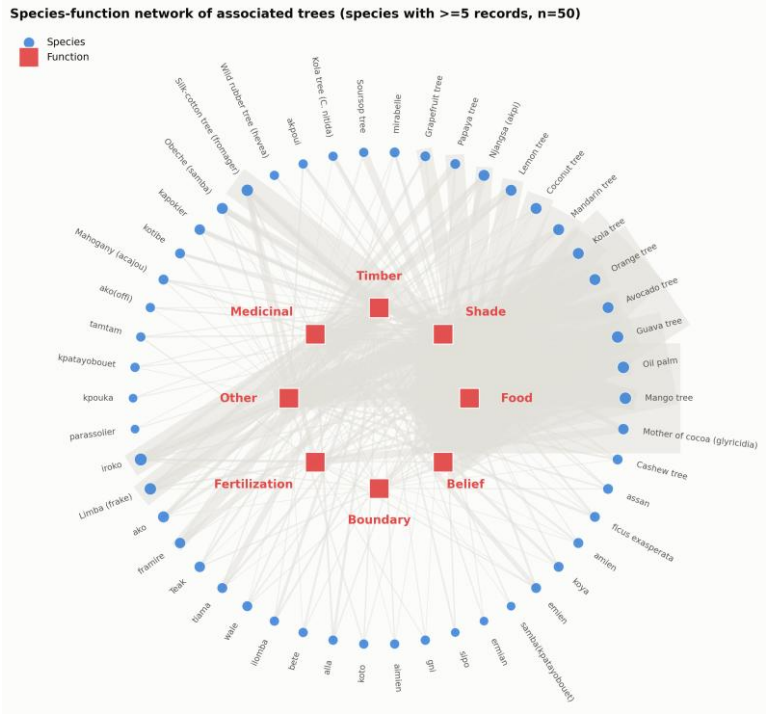
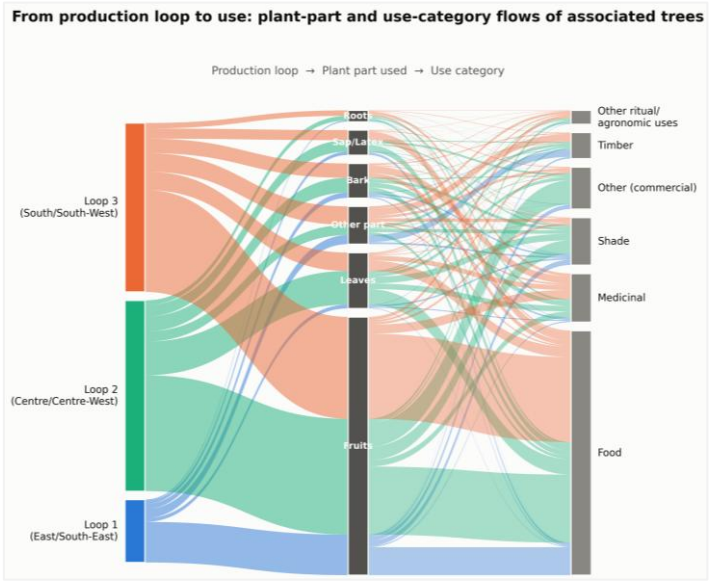


Fig. 6. Species-function bipartite network of associated trees (50 species recorded at least 5 times, out of 387 in total). Red squares represent the eight questionnaire functions; blue circles, species, positioned around their dominant function; edge thickness is proportional to the number of shared records.

A complementary reading of this network, focused not on species but on the loop → plant part → function pathway, is presented as an alluvial diagram (Figure 7). This diagram visually confirms, across the 2349 records with both a declared plant part and function, the predominance of the fruit → food pathway already quantified above, while also showing that the South/South-West loop (in orange) stands out for a greater diversity of secondary plant part–function pathways than the other two loops.



Ribbon width = number of species-use declarations; ribbon colour = production loop of origin. Belief, boundary-marking and fertilization uses (each <2% of records) are pooled as « other ritual/agronomic uses ».

Fig. 7. Production loop → plant part used → use category flows of associated trees (n=4170 organ×use pairs from 2349 records with both a declared plant part and use).

Declared barriers to valuation and farmer preferences

Among the 452 farms, 407 provided a usable answer on difficulties exploiting forest trees; 46 of them (11.3%) report one (Figure 8A). This proportion varies numerically by loop (from 7.1% in the Centre/Centre-West loop to 16.7% in the East/South-East loop), but this difference does not reach the conventional significance threshold (chi-square test, χ^2=5.87, df=2, p=0.053) and should therefore be read as a trend rather than an established effect. Among the 46 farms reporting a difficulty, the overwhelming majority (36/46, 78.3%) describe a conflict with an external third party: a private logger (22 cases) or the Water and Forests administration (13 cases), the remainder being split between logging-related damage (6 cases), an unspecified difficulty (4 cases), and a conflict with a charcoal producer (1 case). In the large majority of cases, this is therefore an access or use-rights conflict with a third party, rather than a technical or commercial constraint.

Thirty-one farms propose a solution; of these, 23 (74.2%) fall under a governance or land/tree tenure logic: regulatory reform (6), prior consultation or consent from the farmer before any felling (6), fair compensation and transparency in exploitation terms (6), clarification of tree ownership rights (3), or outright cessation of industrial logging (2); the remaining eight responses call for state support or technical guidance (4), are off-topic (1), or are not classifiable (3).

Among the same 452 farms, 393 declare at least one preferred forest species and 393 at least one species they would like to remove (Figure 8B, Table 4). Iroko is by far the most frequently cited species as preferred (158 farms), followed by frake (128) and akpi (68); fromager, although cited by 70 farms as preferred, is simultaneously and by a wide margin the species most frequently cited as a candidate for removal (174 farms, versus 23 for iroko

and 86 for samba, the two other species most concerned). Cross-referencing this with each species' functional profile (Table 4) sheds light on this contrast: iroko, the most preferred species, is carried at 63.1% by the timber function and generates monetary or self-consumption value for only 3.6% of its records; its preference thus owes more to the diversity of its uses than to a regular income. Fromager, conversely, is carried at 50.6% by the shade function alone, with only 1.1% of value reported. Akpi, for its part, combines a high preference (68 farms, only 5 removal mentions) with a strongly food-oriented profile (79.0%) and relatively high valuation (24.2% of records with reported value); here, declared preference coincides directly with measured use value.

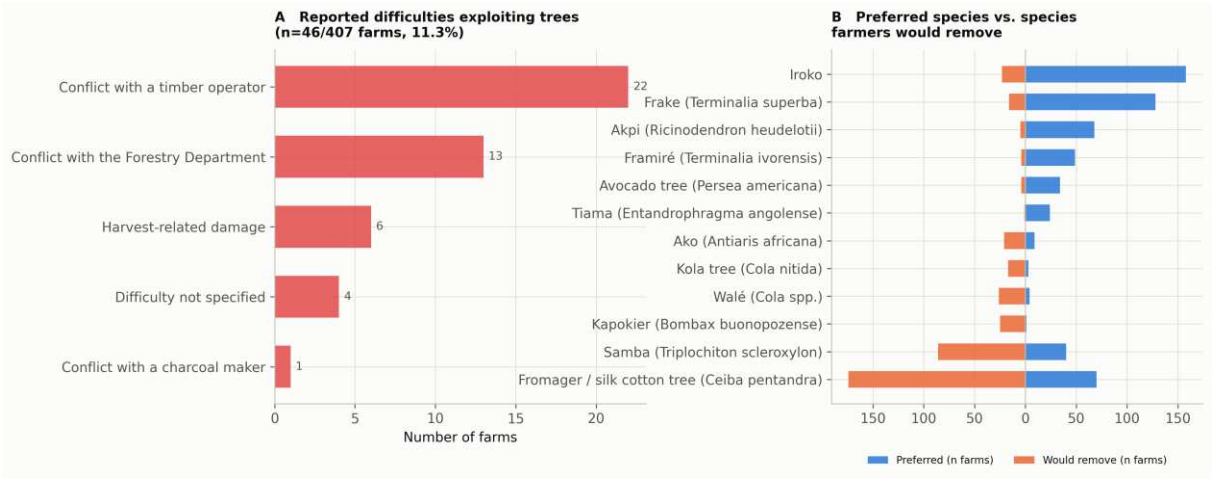


Fig. 8. (A) Difficulties exploiting forest trees reported by farmers (*n*=46/407 farms with an exploitable answer, 11.3%). (B) Species most frequently cited as preferred (blue bars, right) or as candidates for removal (orange bars, left) by farmers (*n*=452 farms), sorted by decreasing net preference.

Table 4. Species most frequently cited as preferred or as candidates for removal by farmers (*n*=452 farms), with their measured functional profile (*n*=3403 species×site records).

Species	Preference (*n* farms)	Removal (*n* farms)	Dominant function (%)	Reported value (%)
Iroko (*Milicia excelsa*)	158	23	Timber (63.1)	3.6
Frake (*Terminalia superba*)	128	16	Timber (64.2)	0.9
Akpi (*Ricinodendron heudelotii*)	68	5	Food (79.0)	24.2
Framiré (*Terminalia ivorensis*)	49	4	Timber (66.7)	2.0
Avocado tree (*Persea americana*)	34	4	Food (94.1)	45.2
Tiama (*Entandrophragma angolense*)	24	1	Timber (75.0)	0.0
Ako (*Antiaris africana*)	9	21	Timber (44.0)	4.0
Kola tree (*Cola nitida*)	3	17	Food (79.9)	30.2
Walé (*Cola spp.*)[1]	4	26	Timber (26.7)	0.0
Kapokier (*Bombax buonopozense*)	1	25	Shade (56.5)	0.0
Samba (*Triplochiton scleroxylon*)	40	86	Shade (40.9)	0.0
Fromager / silk cotton tree (*Ceiba pentandra*)	70	174	Shade (50.6)	1.1

Species sorted by decreasing net preference (*n* preference - *n* removal). Dominant function and reported value recomputed from the underlying species-level summary. Fromager and Kapokier are two distinct vernacular names in the raw data and were not merged. [1]Walé is a vernacular homonym: the project's species taxonomy cross-reference lists three Cola species under this name depending on the respondent's ethnic group (*C. cordifolia, C. gigantea, C. lateritia*), and two raw records carry an explicit scientific-name annotation pointing to two different species among them; reported at genus level (*Cola spp.*) for this reason.

To situate these twelve species within the full functional pool, a hierarchical agglomerative clustering (Ward linkage) was applied to the 50 species in the species-function network (Figure 6), based on their eight-function use profile (% of each species' own records). The classification yields five clearly interpretable groups (Figure 9): a food-dominant group (15 species, 93.8% food function on average, including akpi, the avocado tree and the oil palm), a timber-dominant group (17 species, 54.5% timber on average, including iroko, frake and samba), a small medicinal-dominant group (3 species: amien, emien, koya), a fertilization/shade group of just two species (glyricidia and tamtam, two legumes already known for their soil-improving properties), and a more heterogeneous shade/mixed group (13 species, including fromager and kapokier). This functional grouping directly

mirrors the preference contrast already observed: iroko and frake, the two most preferred species, both belong to the timber group, while fromager, the species most frequently cited for removal, falls in the shade/mixed group, alongside comparable structural species (acajou, kapokier, wild rubber tree), rather than with the sought-after food or medicinal species. Akpi, the only species that is both highly preferred and strongly monetized (Table 4), is accordingly found in the food group, alongside fruit-tree species of comparable commercial value (avocado, mango trees).

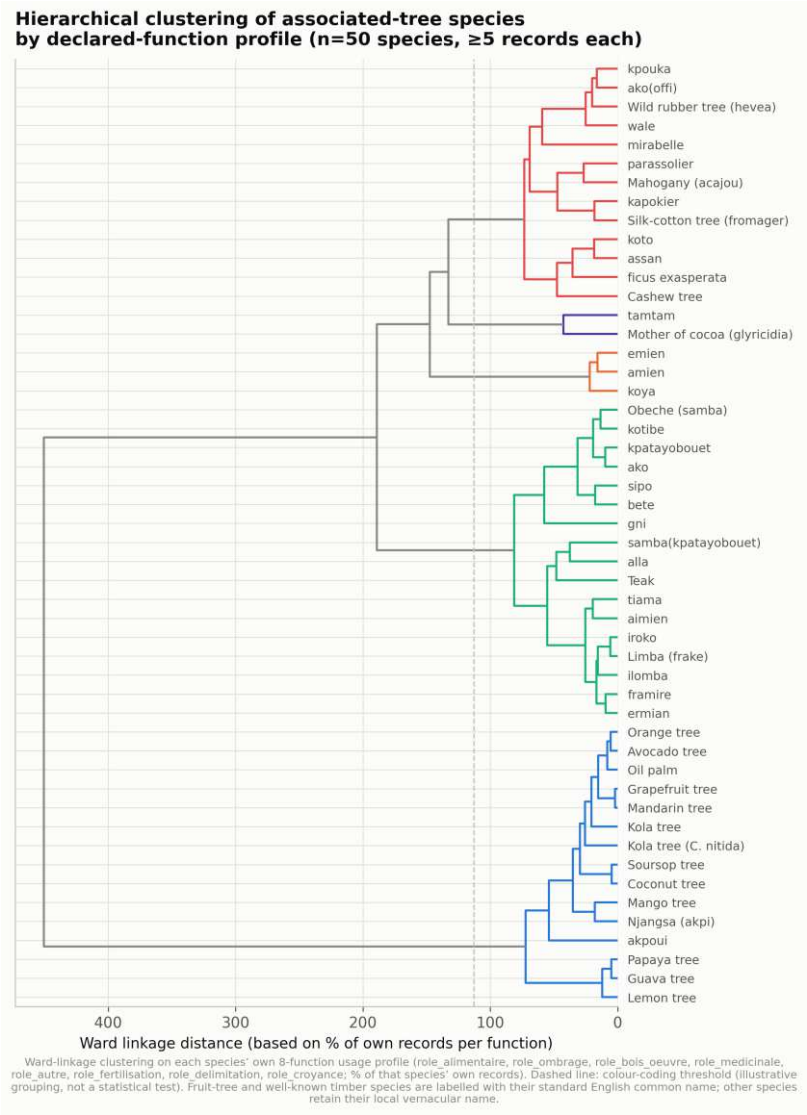


Fig. 9. Hierarchical clustering (Ward linkage) of the 50 associated-tree species recorded at least 5 times, based on their eight-function usage profile (% of each species' own records). Colours mark five illustrative clusters cut at 25% of the maximum linkage distance (not a statistical test); grey links lie above the colour-coding threshold.

Associated-species richness per farm

Associated-species richness declared per farm, made measurable thanks to the complementary sheet described in the methods, averages 7.3 species per farm (standard deviation 3.2; median 7; range 1-24; n=452/452). This richness varies significantly by production loop (Kruskal-Wallis test, H=17.57, df=2, p<0.001), with an increasing gradient from the East/South-East loop (mean 6.2 species) to the Centre/Centre-West loop (7.2) and then the South/South-West loop (8.0), a gradient consistent with the gradient of structural functions (shade, timber) already observed for these same zones.

By contrast, this farm-level richness is associated neither with reporting a difficulty exploiting forest trees (Mann-Whitney test, farms without a difficulty: mean 7.39 species, n=361; with a difficulty: mean 7.37, n=46; U=8441.5, p=0.853), nor with the number of species cited as preferred (Spearman correlation, rho=-0.047, p=0.322, n=451) or as candidates for removal (rho=-0.051, p=0.277) by the same farmer. In other words, the diversity of species actually present on a farm predicts neither the likelihood that a farmer reports a tenure conflict with a third party, nor the extent of their declared preferences or rejections among forest species; a negative result that deserves to be reported as honestly as positive associations, and that reframes the interpretation of declared difficulties as stemming essentially from a governance context external to the farm rather than from its own tree composition.

Discussion

The food function dominates, but varies strongly by geography

The clearest result of this article is the predominance of the food function among trees associated with cocoa farms in Côte d'Ivoire (59.2% of records), largely carried by a small number of fruit-tree species common in this type of agroforestry system (avocado, mango, orange, and oil palm trees). This predominance confirms, at the national scale, the finding already made for West and Central African cocoa agroforestry systems that the composition of associated species responds as much to the household's food and subsistence needs as to market logic (Sonwa et al., 2014). The geographic gradient observed (an increasing food function and decreasing structural functions (shade, timber) from the East/South-East loop to the South/South-West loop, consistent with hypothesis H1 formulated in the introduction) is also consistent with work showing that the choice to keep a spontaneous, remnant, or planted tree in a cocoa farm depends on its origin and on the maturity of the agroforestry system (Konan et al., 2025), two dimensions that themselves vary across the three loops in this study. This gradient nonetheless remains a plausible hypothesis rather than an established causal relationship, as the cross-sectional data used here cannot distinguish between an effect of cocoa-farm age, population density, or a simple artefact of regional floristic composition.

A partial monetization, concentrated on a core of fruit-tree species

Consistent with hypothesis H2, only 23.5% of records report an explicit value (monetary or self-consumption), and this proportion drops to 14.8% for the directly exploitable annual sale amount category alone. This result, far from suggesting an absence of value for associated trees, should be read as evidence of the largely non-market or undeclared nature of this value: timber, for example, is almost systematically harvested without being sold (97.4% with no value reported), suggesting domestic use (construction, firewood, craft) not captured by the questionnaire's income field, rather than a real absence of use value; a distinction between non-market use value and direct monetary value that echoes the well-documented finding, for West and South African non-timber forest products, that their real economic contribution to rural households is structurally underestimated when measured by sales flows alone (Shackleton and Shackleton, 2004). The ranking of species by median sale amount (the oil palm first, followed by akpi and the orange tree, with the avocado tree, despite being the most frequently cited species, ranking in the middle of the table) illustrates that citation frequency and unit market value are two distinct dimensions of a species' socio-economic value, which an analysis limited to abundance alone cannot capture.

The « Other » category: a commercial function rather than a distinct use

Detailed examination of the « Other » function category (questionnaire code 8) shows that it is carried, in 83% of cases, by the same fruit-tree species already classed under the food function, and that 36.0% of its records also report a sale with an annual amount; a proportion markedly higher than that of the food function alone (23.0%). The most parsimonious interpretation is that farmers used this code, in addition to the food code, to specifically flag the commercial purpose (sale) of a fruit already consumed, rather than to denote a use truly distinct from the codebook's eight categories. This reading, which cannot be confirmed with certainty from the available data, illustrates a general limitation in interpreting catch-all categories in survey data and calls for caution in analysing the « Other » function as a substantive category in its own right.

A geographic contrast in valuation to be interpreted with caution

The share of records with a reported value rises from 8.1% in the East/South-East loop to 27.7–29.6% in the other two loops; a numerically striking contrast, but one whose interpretation is complicated by the very uneven recording resolution already noted for this survey sheet (3 localities recorded in the East/South-East loop versus 88 and 28 in the other two zones). More aggregated recording (at the department rather than the village scale) could mechanically reduce the likelihood that a precise individual income is reported and retained in the summary, without this necessarily reflecting a real difference in the economic valuation of trees on the ground. This contrast should therefore be verified, if possible, through a complementary survey targeted at the East/South-East loop before being interpreted as a substantive economic result rather than a data-resolution artefact.

A network structured around a restricted core of multifunctional species

The species-function network reveals a structure consistent with the literature on the valuation of associated trees by West African farmers: a small number of species (here iroko first, followed by several commonly cultivated fruit-tree species) accounts for most of the declared functions, while the vast majority of the 387 recorded species fulfil only one or two functions and appear only rarely in the sample. This concentration is consistent with work showing that farmers' decisions to keep an associated tree follow a logic of multiple use value rather than a one-dimensional economic calculation (Dago et al., 2025), and more broadly echoes the finding made for Amazonian useful flora that a small core of versatile species accounts for most of the use value of a plant community, well ahead of the majority of species with a single or rare use (Phillips and Gentry, 1993b). It suggests that interventions aimed at strengthening the socio-economic value of associated trees would benefit from prioritizing this already widely adopted core of species rather than promoting diversification toward species that are rare in the current system.

A governance barrier, not just a market one, behind the low monetization of timber

The complementary analysis of declared exploitation difficulties sheds direct light on one of this article's most striking results: the near-absence of reported monetary value for timber, already noted above (only 2.6% of records with a timber function report any value). Among the 46 farms reporting a difficulty exploiting forest trees, 78.3% describe a conflict with a third party (a private logger or the Water and Forests administration) rather than a market or technical-skill constraint. This finding echoes an emerging literature on tree tenure in Côte d'Ivoire and across the sub-region: Côte d'Ivoire's 2019 Forest Code reform (Law No. 2019-675) in principle grants landowners ownership of natural trees on their plot, but a recent report documents that loggers continue to bypass this recognition by dealing directly with local customary authorities, sustaining farmers' distrust despite the reform (USAID ILRG, 2021).

A more recent national survey of 228 Ivorian cocoa farmers confirms the persistence of legal restrictions on the sale of wood from natural forest trees, even as agroforestry products (including wood) contribute close to 10% of surveyed farms' income; a sign that demand and commercial potential do indeed exist, but remain constrained by the regulatory framework rather than by an absence of market (Konaté et al., 2026). A structurally identical problem (the state retaining ownership of high-value natural trees regardless of the plot's land tenure status) has been documented in neighbouring Ghana, where it explicitly discourages the adoption of forest-tree-based agroforestry practices (O'Sullivan et al., 2021). Field research conducted in Côte d'Ivoire confirms even more directly that cocoa farmers report repeated, damaging logging activity with no possibility of compensation from the forestry administration, and call for formal agreements before committing to any tree conservation (Kouassi et al., 2021) ; a demand that is echoed, almost word for word, in the solutions proposed by farmers in our own sample (prior consultation or consent, fair compensation, clarification of ownership rights). This convergence suggests that the low monetization of timber observed here does not reflect an absence of commercial demand, but a governance and use-rights problem well documented elsewhere in the sub-region (Tieguhong et al., 2015 , on the broader role of governance in the valuation of non-timber forest products in Central Africa, and Shackleton and Shackleton, 2004 , on the role of these products as a safety net for rural South African households, a role that the low monetization observed here for timber appears to prevent from being fully played in the Ivorian context).

Farmers' declared preferences confirm and nuance the measured use value

Cross-referencing the species farmers declare as preferred or as candidates for removal with their functional profile measured from the species×site records offers a form of external validation of the network results already discussed above. Iroko, the most generalist species in the species-function network and the species most frequently cited as preferred by farmers (158 of 452 farms), is nonetheless monetized for only 3.6% of its records: its perceived value therefore owes essentially to the diversity of its uses (timber, shade, pharmacopoeia, ceremonial status), not to a regular income; a hierarchy of values consistent with work showing that West African farmers' decisions to keep a tree follow a logic of multiple use rather than an immediate profitability calculation (Anglaaere et al., 2011; Dago et al., 2025). Conversely, akpi combines a high preference and few removal mentions with a strongly food-oriented profile and real monetary valuation (24.2% of its records); here, declared preference and measured use value coincide directly. The case of fromager is the most instructive: cited as preferred by 70 farms and as a candidate for removal by 174 others (twice as many), for a profile dominated by shade (50.6%) and near-zero monetization (1.1%). This ambivalence is consistent with a finding documented elsewhere in the West African cocoa belt, where species with high shade value but also a large footprint (wide canopy, competitive root system) are frequently described by farmers as both useful and problematic for cocoa cultivation (Asigbaase et al., 2025; Olatujoye et al., 2025) ; a tension that may reflect differences in local context (cocoa-farm age, existing fromager density) rather than disagreement among farmers over the species' value itself, a hypothesis the current data cannot resolve.

Associated-species richness, now measurable per farm, explains neither declared difficulties nor preferences

The newly gained ability, thanks to the complementary sheet described in the methods, to measure associated-species richness at the scale of the individual farm rather than the aggregated stand makes it possible to directly test a hypothesis that could previously only be formulated, not tested: that of a link between the tree diversity actually present on a farm and how its operator perceives and reports exploitation difficulties or species preferences. The result is negative across all three tests conducted, which reinforces, rather than undermines, the interpretation already proposed above: the difficulties farmers report stem essentially from a governance and tenure context external to the farm (conflict with a logger or the Water and Forests administration), not from an intrinsic feature of its tree composition. The significant geographic gradient in richness per farm (East/South-East < Centre/Centre-West < South/South-West loop), by contrast, qualitatively echoes the gradient already observed for structural functions, suggesting an internal consistency between these two dimensions measured at different scales.

Limitations

Several limitations should be highlighted. First, the very uneven recording resolution between loops, already noted in the methods, limits the strict comparability of zone-level statistics, particularly for the East/South-East loop; the significance tests reported should therefore be read as indicative rather than as definitive proof of a causal geographic effect. Second, the classification of economic valuation, although transparently documented, rests on an interpretive judgement for ambiguous text formats (unit price versus annual amount, self-consumption versus informal sale); replicating this classification with a second, independent coder would strengthen confidence in the categories used. Third, the annual sale amount is available for only a subset of 502 of the 3403 records (14.8%), which limits the statistical power of inter-species and inter-loop comparisons on this variable. Fourth, the unit of observation (species×site) still does not make it possible to link an individual record from the Associated Species Census sheet (n=3403) to the characteristics of the farm it comes from (area, yield, management profile): the complementary sheet used above provides species richness aggregated per farm, reliable at the farm level itself, but does not recover the identity of the originating farm for each species×site record in the main floristic census; the limitation initially noted in the methods is therefore only partially lifted. Fifth, the thematic classification of declared difficulties and solutions rests on a small sample (46 and 31 farms respectively) and on an interpretive judgement of free text; the associated percentages should be read as indicative of a trend rather than as precise estimates generalizable to the whole population of Ivorian farmers. Sixth, the vernacular name walé, frequently cited in farmers' preferences (Table 4), proved to be a homonym covering several *Cola* species depending on the respondent's ethnic group (*C. cordifolia*, *C. gigantea*, and *C. lateritia* all appear under this name in the project's

taxonomic cross-reference table, and two raw records carry a direct scientific-name annotation each pointing to a different species); it is therefore reported at the genus level (*Cola spp.*) rather than at the species level in Table 4.

Conclusion

Across 3403 species×site records covering the three cocoa production loops of Côte d'Ivoire, this study shows that trees associated with cocoa farms primarily provide a direct-use service (food first and foremost « 59.2% of records ») before constituting a generalized source of income: only 23.5% of records report a monetary value, unevenly across zones and concentrated on a restricted core of fruit-tree species already well established in West African agroforestry systems (avocado, mango, orange, and oil palm trees). The most actionable result, however, concerns less the species themselves than the barriers to their valuation: the near-absence of reported sales for timber does not reflect an absence of demand but tenure and access conflicts with third parties (loggers, the Water and Forests administration), for which farmers themselves call for specific solutions ; prior consultation, fair compensation, clarification of ownership rights. Clarifying this regulatory framework is therefore a more direct lever for the economic valuation of associated trees than promoting new species alone: fully recognizing this value calls less for planting new species than for securing the use of those that farmers already cultivate, protect, and value.

Author Contributions

BIA. Developed the methodology, collected survey data, analysed the data and wrote the paper. AAA. Developed the methodology, collected survey data and supervised the work. AME, KKE and DSA supervised the work.

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Declaration of competing interest

The author declare no competing interests.

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Data availability

The datasets analysed as part of this study are available at: Adji, B. I., Assiri, A. A., Assi, M. E., & Kassin, K. E. (2026). Raw survey and floristic inventory data on cocoa-based agroforestry systems in Côte d'Ivoire (three cocoa-growing "loops", 2013-2016): anonymized version [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.22016383

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