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Salient features and ecosystem services of tree species in mountainous indigenous agroforestry systems of North-Eastern Tanzania

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Indigenous agroforestry systems in tropical mountainous environments provide crucial ecosystem services, but these ecosystems are also facing some challenges. A loss of diversity and native tree species in the overstory layer has been a growing concern in agroforestry worldwide, yet the drivers behind it remain inadequately understood. We hypothesize that the choice of overstory tree species is closely linked to the ecosystem services required by farmers, their livelihood strategy, and the salient features of each system. We, therefore, investigated four different farming systems in the mountains of northeastern Tanzania, i.e., the Kihamba on Mt. Kilimanjaro, Ginger agroforestry in the South Pare mountains, and Miraba and Mixed spices agroforestry in the West and East Usambara. In 82 farms, we collected data on the structure, tree species composition (both native and non-native), diversity, and associated provisioning ecosystem services as identified by smallholder farmers. Our results indicate that although all studied systems are multi-layered with three or four vertical layers, they have notable differences in their salient features concerning structure, composition, and diversity. The unique climate, landscape setting, soil, historical background, and economic opportunities that exist in each region contribute to those differences. Our findings indicate that the Kihamba system had the highest number of native tree species, and the largest diversity in species used for provisioning services, followed by Ginger agroforestry. No native species were used in Miraba or Mixed spices agroforestry, where a limited number of non-native tree species are planted mainly for fuel and timber or as a crop, respectively. Our findings regarding reported provisioning ES corroborate our hypothesis and imply that policies to increase resilience and restore the native tree species cover of the agroforestry systems of Tanzania can only be successful if knowledge of the ES potential of native species is increased, and interventions are tailored to each system's ES needs for conservation as well as livelihood.

KEYWORDS

smallholder indigenous farming systems, agroforestry systems, Kihamba, homegardens, vernacular names tree species, ecosystem services, mountain ecosystems, Tanzania

1 Introduction

Mountain ecosystems in the tropics are important for the provision of ecosystem services, both on-site as to regions that are downhill (Grêt-Regamey et al., 2012; IPBES, 2019). Trees and forests are essential to those ecosystem services, given their positive effects on erosion control and slope stabilization, biodiversity, water buffering, nutrient cycling, carbon sequestration, microclimate and supporting other biodiversity, as well as harboring culturally important sites (e.g., Padilla et al., 2010; Hirschi et al., 2013; Pătru-Stupariu et al., 2020). In northeastern Tanzania, mountain ecosystems contain important conservation landscapes, including forest reserves and national parks with high species diversity and of international importance (Lovett and Wasser, 1993; Lovett, 1998; Burgess et al., 2007; Heckmann, 2011).

However, tropical mountain ecosystems are also facing growing environmental, social, and economic challenges as short-term needs in terms of livelihood and food security may conflict with conservation goals despite a local understanding that these goals benefit the community in the long run (Hamilton and Bensted-Smith, 1989; Kimaro et al., 2018; Glushkova et al., 2020; Kimaro and Chidodo, 2021). Indigenous agroforestry systems have been praised as a promising avenue for balancing those needs and as a model for climate-smart agriculture (Negash et al., 2012; FAO, 2022; Kassa, 2022). If properly managed, these ecosystems can play an important role in conservation efforts and simultaneously provide regulating, supporting, and cultural as well as provisioning ecosystem services (ES; Kuyah et al., 2016, 2017). In Tanzania, indigenous agroforestry systems support regions with large population densities (ranging from 150 to 350 persons/km^2 (URT, 2013); 90% of them being smallholder farmers; Mattee et al., 2015). On the other hand, agroforestry systems are also at risk of environmental degradation associated with poverty and are vulnerable to the effects of climate change (FAO and UNCCD, 2019). Recent studies about the mountains of northeastern Tanzania have focused on specific aspects, such as soil organic carbon (Winowiecki et al., 2016; Kirsten et al., 2019), erosion (Wickama et al., 2014), dynamics of land use change (Hall et al., 2011), and land management and livelihoods (Lundgren, 1980; Reyes, 2008). Nevertheless, the term 'agroforestry' as a collective name for 'land-use systems where woody perennials are deliberately used on the same land-management units as agricultural crops and/or animals (FAO, 2015)' holds danger for generalization: In northeastern Tanzania, indigenous agroforestry systems considerably differ in their farming traditions, livelihood strategies, structural arrangement and choice of crops, animals or overstory species as well as in soils, rainfall, and landforms. Few studies have considered the interaction between those differences in salient features and the delivery of ecosystem services (Michon et al., 1983, 1986; Abebe et al., 2013).

The overstory layer is one of the important features in multi-layer agroforestry systems due to its influence on multiple ES (Soini, 2005; Graham et al., 2022). Nonetheless, the overstory layer is undergoing many changes in agroforestry systems around the globe (Pantera et al., 2021). In Africa, many homegardens are being transformed and native tree species are being replaced by non-natives for timber production (Yakob et al., 2014; Endale et al., 2017; Wagner et al., 2019; Gemechu et al., 2021). The increasing dominance of agroforestry canopies by fast-growing non-native tree species is a consequence of colonial governance in the period of 1900–1970 (von Hellermann, 2016), a bias toward production services and a focus in research and extension on species providing fodder or fixing nitrogen (Atangana et al., 2014; Franzel et al., 2014). Non-native species provide fewer ES because they score lower in terms of multifunctionality (van der Plas et al., 2016; Castro-Díez et al., 2019, 2021). Their increased share in agroforestry canopies is considered a signal of indigenous agroforestry degradation (Oginosako et al., 2006; Lelamo, 2021). Examples of non-native species with a negative effect include *Eucalyptus* spp. (acidification, water reserve, and nutrient depletion; Castro-Díez et al., 2012; Silva et al., 2017); *Acacia mearnsii*, *Leucaena leucocephala*, and *Persea americana* (biodiversity decline; Vilà et al., 2011; Sharma et al., 2022); and *Cedrela odorata* (native tree suppression; FORCONSULT, 2006). In Tanzania, common examples of non-native trees in homegardens include *Eucalyptus saligna*, *Pinus patula*, *Cedrela odorata*, *Acacia mearnsii*, *Grevillea robusta*, *Persea americana*, and *Leucaena* spp. (Lyimo et al., 2009). These species are promoted for provisional services, i.e., timber provision, fuel, food, and fodder, yet minimally contribute to regulating (water regulations, pollination, climate), cultural (esthetic values, heritage, recreation, and ecotourism), or supporting (nutrient cycling or soil formation) ES (Munishi et al., 2008; Lyimo et al., 2009; Negash et al., 2012; Abebe et al., 2013).

Despite the growing concern about this loss of native species and their services, governments in developing countries lack strategies for restoring native tree species in agroforestry systems at the landscape scale (FAO, 2013). Furthermore, such strategies have little chance of success if they are not tailored to the specific livelihood strategies and salient features of different types of agroforestry systems in different regions, nor to the drivers and ES requirements that are behind the choices that people make for their homegardens and fields. Hence, in this study, we focus on the internationally renowned (Kitalyi et al., 2013; FAO, 2022) yet rapidly transforming indigenous agroforestry systems in the mountains of northeastern Tanzania, i.e., in the Kilimanjaro, South Pare, and West and East Usambara region (cf. Munishi et al., 2008; Hall et al., 2011; Molla and Kewessa, 2015; Brus et al., 2019). We hypothesize that the choice of overstory tree species is closely linked to farmers ES needs, livelihood strategy, and the salient features of each system. To assess that hypothesis, we visited 82 smallholder farms to identify the structure and different components, i.e., crops, animals, and perennials, and discuss their roles in the livelihood strategy of the farmers. Next, we quantified the identity and diversity of the different trees in the canopy of each system. Finally, we discussed the different perceived ES services farmers require from those trees and how they relate to the salient features of each system. This information can guide future policies and campaigns to improve the canopy biodiversity to be in sync with the needs and preferences of the farmers in each region.

2 Materials and methods

2.1 Study area

Agroforestry in northeastern Tanzania is practiced on Mount Kilimanjaro, in South Pare, and in the West and East Usambara Mountains, each occupying an agricultural area of approximately 8,000 km^2 (Figure 1; Burgess et al., 2007; Heckmann, 2011;

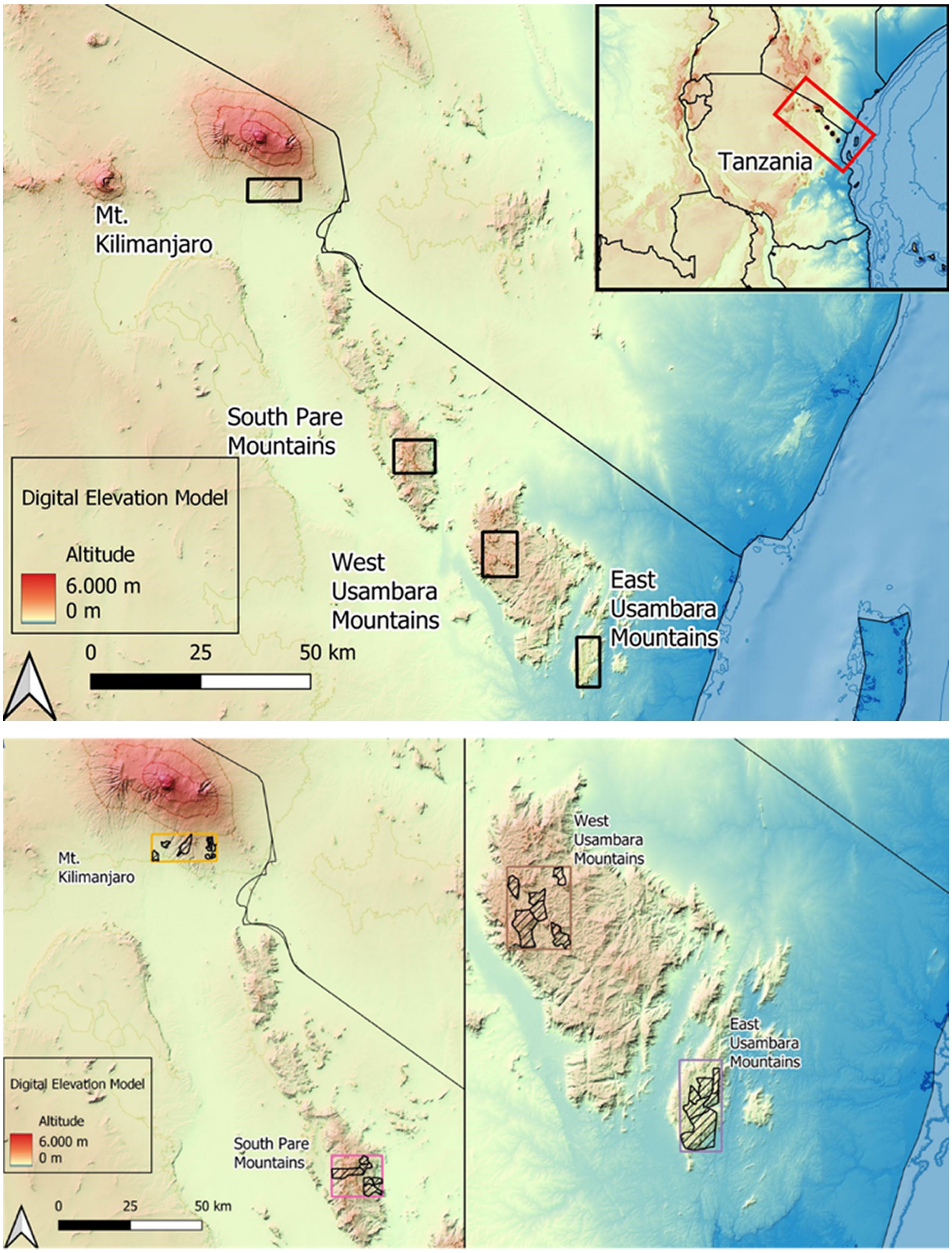

FIGURE 1
Location of the studied areas (top) and selected wards (bottom) in the northeastern mountains of Tanzania.

Zech et al., 2014) with elevations ranging from 800 to 2,000 m asl. The climate is humid and monsoonal. Annual rainfall has a bimodal distribution with the main rainy season occurring between March and June (locally called *Masika*) and a shorter rainy season from October to December (*Vuli*). Each mountain range has its own unique indigenous agroforestry system (Akinnifesi et al., 2008; Reetsch et al., 2020a,b). These mountain ranges are referred to as 'Kihamba' or 'Chagga homegardens' on the southern slopes of Mount Kilimanjaro (Hemp and Hemp, 2008; Banzi and Kalisa, 2021), 'Ginger agroforestry' in South Pare (Ndaki, 2014; Mmbando, 2015), 'Miraba' in West Usambara (Msita, 2013), and 'Mixed spices agroforestry' in East Usambara (Hall et al., 2011; Patel et al., 2022).

2.2 Data collection

2.2.1 Site selection

For each mountain range, an area of *ca.* 200 km^2 was demarcated (Figure 1), comprising six representative administrative wards (local government areas; Figure 2). In each ward, plots of 0.2–0.5 ha were demarcated in randomly selected household farms. In total, 82 plots were selected, i.e., 35 in Kihamba, 18 in Ginger agroforestry, 20 in Miraba, and 9 in Mixed spices agroforestry. For each area, mean annual rainfall and temperature were derived using Modern-Era Retrospective Analysis for Research and Applications (MERRA-2) and Geodetic Earth Orbiting Satellite GEOS 5.12.4 from the Prediction of Worldwide Energy

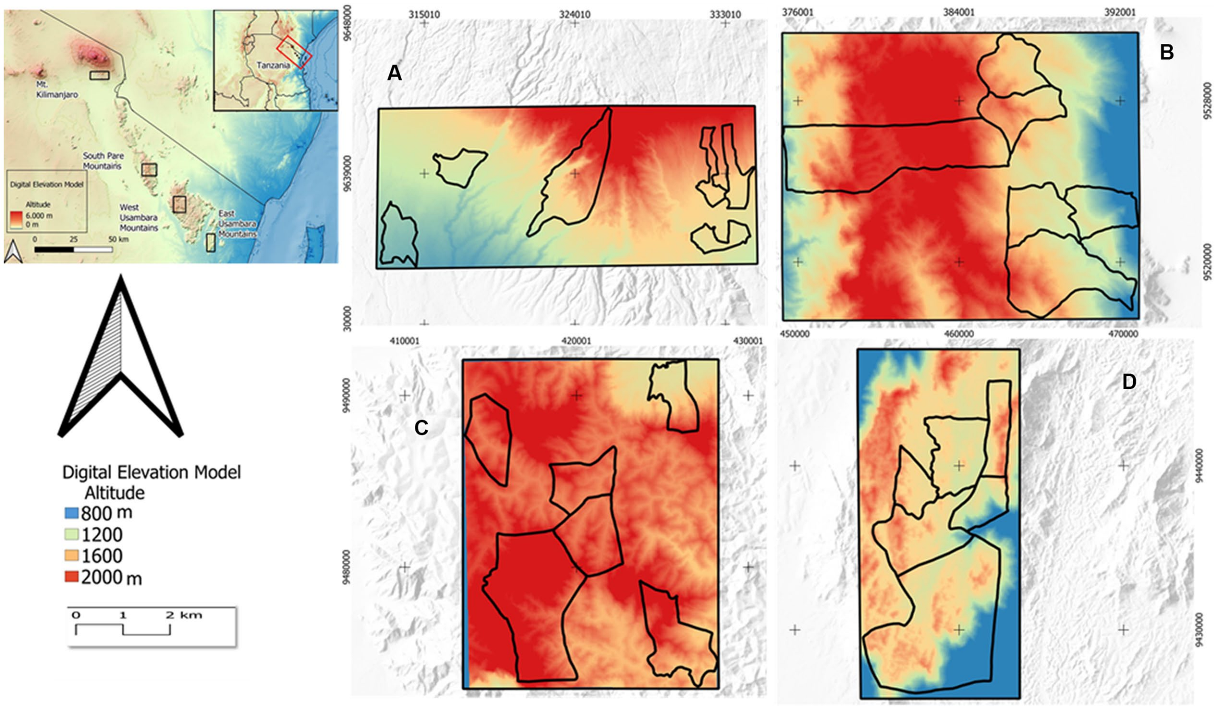

FIGURE 2
Detailed boundaries and location of administrative wards within each study landscape: **(A)** Mount Kilimanjaro; **(B)** South Pare Mountains; **(C)** West Usambara Mountains; **(D)** East Usambara Mountains. Boundaries and location of administrative wards were generated using QGIS 3.16.6 with GRASS 7.8.5 software.

Resources (POWER) database [Global Modeling and Assimilation Office (GMAO), 2015]. Landform and soil information were derived from the Harmonized World Soil and SOTER Databases (FAO, 2016) and the WoSIS database in SoilGrids (ISRIC, 2023), complemented by own field observations. The data are presented in Table 1.

2.2.2 System structure and tree species composition in the indigenous agroforestry systems

We conducted a field survey from July to September 2021, collecting data on salient features of each agroforestry system (i.e., vertical structure (number of layers and canopy depth), horizontal arrangement, mixing patterns and management aspects, and species composition; cf. Michon et al., 1983; Hemp and Hemp, 2008; Dhanya et al., 2014). The canopy depth was assessed by a tape measure and clinometer (cf. Leonard et al., 2010; Kanmegne-Tamga et al., 2023), and photographs of farm plots were taken at the eye level during the daytime to document structure and arrangement. All photographs were taken at 50 m from the predominant agroforestry layers. Tree species (both vernacular and botanical names) were identified with the help of plot owners, botanists from Tanzania Forest Research Institute, digital photo interpretation [PlantNet] app, 2021 (Goëau et al., 2013), and vegetation identification guides (Mbuya et al., 1994; Maundu and Tengnäs, 2005; NAFORMA, 2010; Thijs et al., 2014).

To verify livelihood strategies and management aspects, we consulted with four key people from each ward in a focus group discussion, including a village executive officer, a ward executive officer, an agricultural extension officer, and senior/experienced smallholder farmers (Appendices 1, 2). In addition, we complemented that information with 82 household interviews (see section 2.2.2; interviews and open-ended questionnaires) where farmers were asked about local management techniques carried out on their farm plots, such as indigenous irrigation, application of farmyard manure, green manure, mulches, opening the tree canopy, lopping, and spacing out the banana stools (cf. Sabbath, 2015; Reetsch et al., 2020a,b).

2.2.3 Ecosystem services in the indigenous agroforestry systems

At each farm plot, a household representative was interviewed using a semi-structured questionnaire to identify farmers' perceptions and needs regarding ES provided by the canopy layer in the system. This study focused on ES relevant for production (food, fodder, fuel wood, timber, and shade) as most essential to the livelihood strategies of smallholder farmers (Fisher and Turner, 2008; Kuyah et al., 2016, 2017; Mkonda and He, 2017; Wagner et al., 2019). Each ES was ranked by smallholder farmers using the 3-point Likert ordinal scale (1 = not important, 2 = important, 3 = most important) for each of the trees identified on their plot (Munishi et al., 2008).

2.3 Data analysis

2.3.1 Stand structure and species composition in the indigenous agroforestry systems

We developed schematic profile representations of the canopy depth of the dominant multi-layer agroforestry systems based on the field photographs using Adobe Photoshop with the aim to better visualize layers and distinguish tree species and canopy depth (cf. Reetsch et al., 2020a,b).

TABLE 1 Climatic and topographic characteristics of the areas included in the study.

	Mt. Kilimanjaro	South Pare Mountains	West Usambara	East Usambara
Studied area	212 km^2	252 km^2	243 km^2	209 km^2
Agroforestry type	Kihamba	Ginger agroforestry	Miraba	Mixed spices agroforestry
Altitude	800–2,000 m asl	1,200–1,800 m asl	1,300–1,800 m asl	800–900 m asl
Mean annual rainfall	1,890 mm	1,000 mm	1,700 mm	1,920 mm
Mean annual temperature range	16–19°C	15–20°C	17–18°C	17–24°C
Landform	Foot ridges and very steep riverside valley slopes	Dissected plateau, rolling to hilly relief, slopes ranging from 10 to 40%	Ridges, steep to very steep slopes, narrow and broad U-shaped valley bottoms	Ridges, steep to very steep slopes, narrow V-shaped valley bottoms
Soils	Nitisols and Cambisols on volcanic material	Acrisols and Leptosols on old precambrian basement rocks	Acrisols and Alisols on old precambrian basement rocks	Acrisols and Alisols on old precambrian basement rocks
Selected wards	Uru North & South; Mbokomu; Kilema central; Marangu West & East	Bombo Mvaa & Mjema; Mtii; Lugulu & Kanza; Chome	Lukozi, ndabwa; Manolo; Mwangoi; Shume; Kwai	Amani shebomeza, Magoda & mlesa; Kisiwani; Mbomole; Misalai
Number of selected household farm plots	35	18	20	9
Field/homegarden size range (ha)	0.2–0.5	0.2–1	0.2–0.5	0.2–1

We used descriptive statistical analyses from R software (3.6.3 version, R Core Team, 2021) and data visualization packages psych and ggplot2 (Nordmann et al., 2022) to explore the distribution of tree identity (native and non-native) and their provisioning of multiple ES within and across the studied systems. We excluded Mixed spices agroforestry because the upper canopy only consists of one non-native tree species (clove, see also Pungar et al., 2021).

2.3.2 Tree species diversity

For each smallholder farm, we calculated tree species diversity, richness, and evenness using the Shannon and Weaver (1963) index of diversity (Eq. 1; Admas and Yihune, 2016; Patel et al., 2022) and Shannon's equitability (E_H) index (Eq. 2),

Shannon index (H′):

$$H' = -\Sigma(Pi)\ln(pi) \qquad \text{(Eq. 1)}$$

Shannon equitability index E_H:

$$E_H = H' / Hmax = H' / \ln S \qquad \text{(Eq. 2)}$$

where H′ is index of species diversity, pi is proportion of total sample belonging to i-th species, lnS is (S = number of species encountered), and Hmax is the highest possible species diversity value.

We also used Sorenson's coefficient index to determine similarities between the identified tree species in two adjacent systems with similar characteristics in terms of multi-layer vegetation composition and local management (McCune and Grace, 2002; Eq. 3),

$$\text{Sorenson's coefficient}\,(CC) = 2C / L1 + L2 \qquad \text{(Eq. 3)}$$

where *C* is the number of tree composition the two AGF landscapes have in common, *L1* is the total number of tree composition found in a system/area1, and *L2* is the total number of tree composition in system/area 2.

Sorenson's coefficient gives a value between 0 and 1, and the closer the value is to 1, the more the systems have in common, with the value of 1 indicating complete overlap in species and a value of 0 indicating two systems are completely different in species composition (Clarito et al., 2020).

2.3.3 Ecosystem services in the indigenous agroforestry systems

We used descriptive and non-metric multi-dimensional scaling (NMDS) approaches in R (Dexter et al., 2018) to analyze the perceived ES offered by the different tree species (Kenkel and Orloci, 1986; Ampoorter et al., 2015). In the NMDS plot, the closer the points are together in the ordination space, the more the similar are their ecosystem communities (Lefcheck, 2012; Buttigieg and Ramette, 2014). The function metaMDS command from the vegan package (Oksanen et al., 2020) in R, coupled with Bray–Curtis similarity and dissimilarity metric calculation between samples (Bray and Curtis, 1957), was deployed for suitable ordination to run the NMDS and check for the homogeneity of the variances (i.e., tree species), respectively (Pot et al., 2022). We used R package ggplot2 to plot the ordination graph. We assessed differences in the ES offered by the different tree species using the permutation test (PERMANOVA) to assess whether differences were significant.

3 Results

3.1 Salient features and livelihood strategies of the indigenous agroforestry systems in the study areas

3.1.1 Kihamba (Chagga homegardens) on the southern slopes of Mount Kilimanjaro

Agroforestry farms at Mt. Kilimanjaro are managed according to the traditional homegarden system of the Chagga tribe, known as

'Kihamba.' The plots in our study typically consisted of a complex, four-layered system (Figure 3): The first layer is a canopy of trees with a canopy depth ranging from 12 to ≥30 m. In the plots in our study, the most common native tree species in the tree layer include *Maragaritaria discoidea*, *Bridelia micrantha*, *Albizia schimperiana*, *Cusonia holstii*; *Rauvolfia caffra*, *Ficus natalensis*, *Cordia africana*, and *Croton macrostachyus* (Table 2; Figure 3; Supplementary Table S1). Common non-native species include *Grevillea robusta, Magnifera indica* (mango), *Persea americana* (avocado), *Artocarpus heterophyllus* (jackfruit), and *Eriobotrya japonica* (loquat). Some evergreen climbing species, such as oysternut (*Telfairia pedata*) and vanilla (*Vanilla planifolia/polylepis*), are grown with the trees as support.

The second layer is a dense upper perennial herb layer, mainly comprising banana varieties (*Musa* sp.) with a canopy depth of 2.5–5 m. The third layer mainly comprises coffee (*Coffea arabica*) with a few young trees, shrubs, and taller herbs making a canopy depth of 1–2.5 m, and the fourth layer consists of annual food crops, mainly beans (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta*), maize (*Zea mays*), cocoyam (*Colocasia esculenta*), and potato (*Ipomoea batatas* (L.) Lam. and *Solanum tuberosum*). These are complemented by nduu (*Dioscorea bulbifera*), shia (*Dioscorea alata*), and biringanya (*Solanum melongena*). Herbs, shrubs (*Dracaena steudneri*; *afromontana* and *fragrans*), and grasses (*Drymaria cordata*, *Setaria splendida*) are grown in fallow gaps. The canopy depth of this last layer ranged from 0.2 to 1 m. The spatial arrangement of the components has no clear pattern

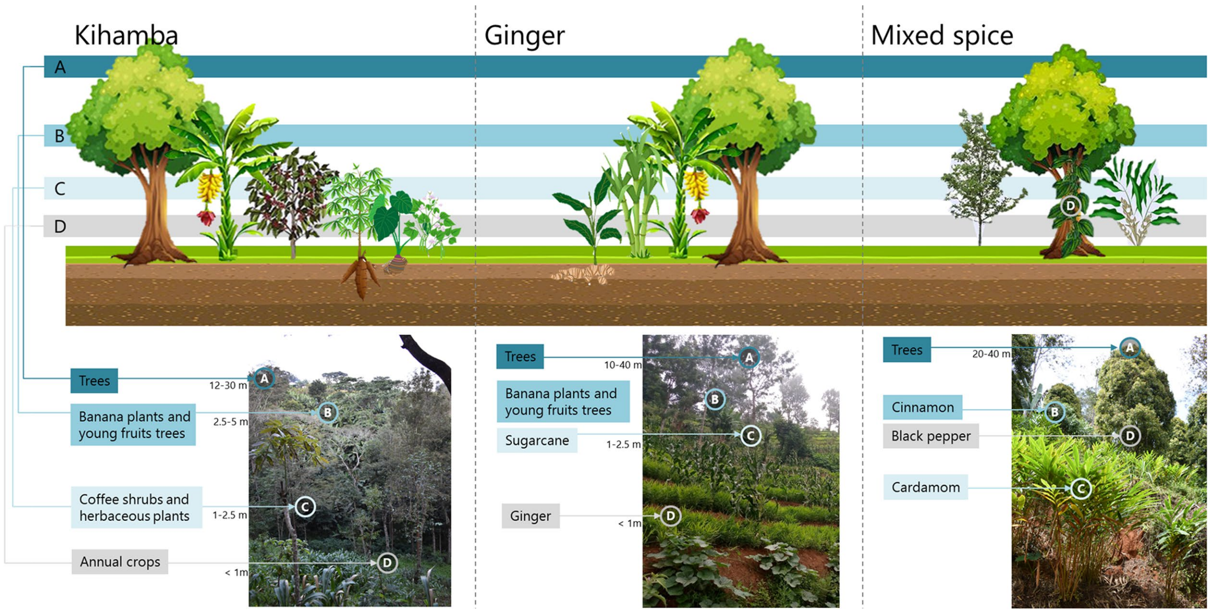

FIGURE 3
Overview of different homegarden agroforestry systems in mountain regions of Tanzania: Kihamba (left), Ginger (center), and Mixed spices agroforestry (right). For each agroforestry system, the main vertical layers are illustrated; for example, for the Ginger agroforestry: A = Trees (first layer); B = Banana (second layer); C=Sugarcane (third layer); D = Ginger (fourth layer; photographs by O. D. Kimaro, August 2021). The structure of Miraba, which is not a homegarden system, is depicted in Figure 4.

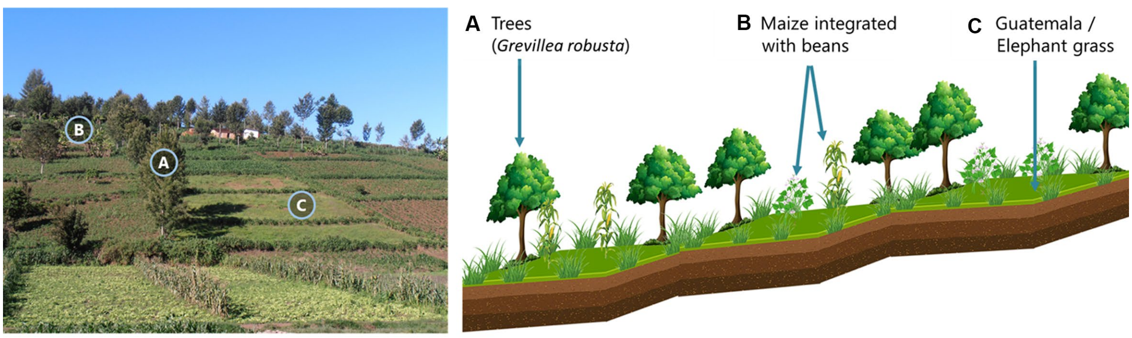

FIGURE 4
Miraba agroforestry in the West Usambara Mountains: A = trees (first layer); B = banana and cassava patches near settlements (second layer); C = strips of Guatemala or elephant grass, maize, and beans inside the square (third layer; photograph by O. D. Kimaro).

TABLE 2 Scientific and vernacular names of tree species recorded in the studied agroforestry systems for the Kilimanjaro (Kihamba, Chagga language), Pare Mountains (Ginger agroforestry, Pare language), and Usambara Mountains Miraba and Mixed spices agroforestry (Sambaa language).

		Vernacular names	
Tree species	Chagga	Pare	Sambaa
Native species			
Albizia schimperiana Oliv	Mfuruanje, Mruka	Mririgwi, Mshai, Mruka	
Bridelia micrantha (Hochst.) Baill.	Mmarie	Mwira	
Cordia africana Lam. (*C. abyssinica* R. Br.)	Mringaringa	Mringaringa	
Commiphora zimmermannii (C. Zimmermann)	Mfifina		
Croton macrostachyus Hochst. ex Delile	Mfurufuru		
Croton megalocarpus Hutch.		Muhande, Irisa, Mfurufuru	
Cussonia holstii Harms ex Engl.	Mnengere		
Ficus Vallis-Choudae Del.	Mkuu	Mkuu	
Ficus natalensis Hochst.	Mfumu		
–		Ihoko	
Lannea schweinfurthii (Engl.) Engl.	Mshishina		
Maragaritaria discoidea (Baill.) G.L. Webster	Mshamana		
Markhamia lutea (Benth.) K. Schum.	Mtalawanda	Mtaanda	
–		Mhodo	
Mitragyna rubrostipulata (K. Schum.) Havil.	Mkundukundu		
Newtonia buchananii (Baker) Gilbert & Boutique		Mririgwi, Mhashita	
Olea capensis L.	Mloliondo/Mchiio		
Pterocarpus angolensis DC.		Mninga wa kipare	
Rauvolfia caffra Sonder	Msesewe, Mwembemwitu, Mkufi		
Syzigium guineense (Willd.) DC		Mlama	
Tarenna pavettoides (Harv.) Sim		Kitundu	
Telfairia pedata (Sims) Hook.	Oysternut, Kweme	Oysternut, Kweme	
Trichilia dregeana Sond.		Mgolimazi wa mzitui, Nduruma, Mtimaji	
Vangueria madagascariensis J.F.Gmel.	Ndowiro		
Non-native species			
Annona senegalensis Pers.		Mtopetope	
Acacia mearnsii De Wild. (black wattle)			Miwati, Mgamadume, Mblakiwato
		Mhache	
Artocarpus heterophyllus Lam. (Jackfruit)	Mfenesi	Mfenesi	
Calliandra calothyrsus Meissner	–		
Callistemon citrinus (Curtis) Skeels	Lemon, Bottle brush		
Calotropis procera (Ait.) Ait. F.		Mkaburi, Jatropha	
Carica papaya L. (papaya)	Mpapai		
Cedrela odorata L. (Spanish cedar)		Mvuje, Mwerezi, Mtikunuka	
Cedrus libani A. Rich. (Libanon cedar)	Mierezi		
Cinnamon zeylanicum Bl. (cinnamon)		Mdalasini	
Citrus limon (L.) Burm. f. (lemon)		Mlimau, Ndimu	
Citrus sinensis (L.) Osbeck (orange)		Mchungwa, Ichungwa	
Cupressus lusitánica Mill. (cypress)			Mtarakwa, Mkrisimasi

(Continued)

TABLE 2 (Continued)

		Vernacular names	
Tree species	Chagga	Pare	Sambaa
Eriobotrya japonica Lindl. (loquat)	Sambia, Loquat	Sambia, Loquat	Msambia
Eucalyptus spp			Mkaratusi
Eucalyptus camadulensis Dehnh., Cat. Pl. Hort.	Mkaratusi/Opani		
Eucalyptus saligna Smith		Mkaratusi	
Grevillea robusta A. Cunn. ex R. Br.	Mkawilia, Mkerewila, Mweresi	Mgrevillea, Mieresi	Mkarela/Mgrevillea
Leucaena leucocephala (Lam.) de Wit	Mlusina		
Malus domestica (Suckow) Borkh. (apple)			Apple
Mangifera indica L. (mango)	Mwembe	Mwembe	Mwembe
Passiflora edulis Sims. (passion fruit)	Isapiku/Ikungu		
Persea americana Mill. (avocado)	I, Mparachichi	Embe, mafuta	
Pinus patula Schldl. Et Cham. (pine)	Msonobari, msindano		Msindano
Prunus persica (L.) Batsch. (peach)	Mpichi	Mfyoski	
Psidium cattleianum Sabine (cattly guava)		Mpera wa kizungu/Ng'ombe	
Psidium guajava L. (guava)	Mpera	Mpera	
Sechium edule (Jacq.) Sw. (chayote)	Chayote/Chocho		
Syzygium aromaticum (L.) Merr. & Perr. (clove)			Mkarafuu

"-" denotes not encountered.

and is irregularly spaced, with trees, shrubs, and arable crops closely intermixed (Figure 3). Most farms have a livestock component in the homegarden, consisting of only a few animals. These farms include typically 2–3 dairy cows and other animals, including pigs, goats, or local poultry and African stingless bees.

For their livelihoods, farmers traditionally depend mainly on coffee and bananas for cash, but due to low coffee prices, the sale of fruits, milk, or honey has become more important. The bananas and arable crops are grown for subsistence, while herbs, grasses, and some woody species are used for fodder or as medicinal plants. Farm management includes lopping the canopy for firewood or for increasing light to the lower layers (e.g., for ensuring better fruiting of the coffee) and spacing out banana stools. Irrigation is also common, where each homegarden is connected to a network of indigenous irrigation furrows. The application of cattle manure as a mulching material to improve soil fertility also was a common practice for many smallholder farmers.

3.1.2 Ginger agroforestry in South Pare Mountains

Ginger agroforestry, practiced in South Pare Mountains (as shown in Figure 3), also consists of four layers, but, as compared to Kihamba, the upper canopies are much less dense (as seen in Figure 3). The first layer consists of trees with a canopy depth ranging from 10 m to over 40 m. The common native tree species in this layer include *Trichilia dregeana*, *Syzigium guineense*, Mguthuru, *Newtonia buchananii*, *Tarenna pavettoides, Markhamia lutea, Croton megalocarpus, Cordia africana, Albizia schimperiana,* and *Ficus Vallis-Choudae* (Table 2; Supplementary Table S1). Common non-native tree species include jackfruit, avocado, mango, loquat, and *Grevillia robusta.*

The second layer consists of sparsely scattered bananas (canopy depth of 2.5–5 m), followed by a third layer with a canopy depth of 1–2.5 m is characterized by mixed shrubs, (*Dracaena* spp. and *Vernonia subligera*). Sugarcane (*Saccharum officinarum*) and maize (*Zea mays*) are also part of this layer. Few smallholder farmers (< 5%) integrate shade coffee into this layer. Our observations showed that the spatial arrangement of the components is irregular, haphazard, and sparsely intermingled. The lowest layer, with a canopy depth of 0.5–1 m, is densely occupied with ginger (*Zingiber officinale*), an underground stem herb plant rotated with arable crops, such as maize and dry beans (*Phaseolus vulgaris*). Few farmers include a few animals, such as a cow (low zero grazing and extensive grazing on fallow gaps) and local chicken breeds.

For their livelihoods, farmers mainly depend on the cultivation of ginger for cash, which was introduced in the area in the 1980s as an alternative for coffee on the dryer and more acidic soils of the Pare mountains, following the collapse of coffee prices and growing disease pressure. The yield is complemented by fruits, sugarcane, and arables. Farm management includes local pipe irrigation. Manure is in short supply and sometimes bought from the lowlands.

3.1.3 Miraba agroforestry in West Usambara Mountains

The West Usambara Mountains have a very different cultural tradition as compared to the Kilimanjaro and South Pare areas. A cultural heritage system called 'Miraba' (literally meaning 'squares') is a farming system that integrates grassy hedges in the landscape (see Figure 4). Originally practiced by women in gaps in the forest, it was later reintroduced in soil and water conservation programs to control erosion that also promoted the use of nitrogen-fixing species, such as Grevillia. Miraba can be considered as a three-layer system with a very sparse, scattered, and linear first layer, consisting of trees with a canopy depth ranging from 20 m to 40 m.

Only non-native tree species were encountered including *Grevillea robusta*, cypress (*Cupressus* spp.), pine (*Pinus patula*), loquat (*Eriobotrya japonica*), black wattle (*Acacia mearnsii*), and *Eucalyptus* spp. (see Tables 2, 3). The second layer of patches of bananas and cassava (*Manihot esculenta*) is only present near or around settlements. The third layer consists of squares of low, grassy hedges of Guatemala and Elephant grass (*Tripsacum andersonii* and *Pennisetum purpureum*). In between the hedges, maize (*Zea mays*), dry beans (*Phaseolus vulgaris L.*), and Irish potatoes (*Solanum tuberosum*) are the most common arable crops.

Contrary to the Kihamba, Ginger, and Mixed spices agroforestry, Miraba is not a system of homegardens. Due to lower rainfall, acidic soils, and connections to the vegetable markets of Tanga, Dar es Salam, and Kenya, households rely mainly on vegetables grown in valley bottoms for cash and on the Miraba on the slopes for subsistence foods. Animal husbandry is not common, and grasses from the hedges are often sold. Some farmers use shrub leaves, such as *Tithonia diversifolia* (Alizeti Pori) and *Vernonia myriantha* (Tughutu) as mulching materials in the Miraba field plots.

3.1.4 Mixed spices agroforestry in the East Usambara Mountains

The 'Mixed spices' agroforestry system of the East Usambara Mountains is a smallholder farming system targeted at growing clove (*Syzygium aromaticum*), cinnamon (*Cinnamomum verum*), cardamom (*Elettaria cardamomum*), and black pepper (*Piper nigrum*). Our study found a dense three-layered system (Figure 3) with an irregular layout of components closely intermingled in space. The first layer consists of clove trees with a canopy depth ranging from 8 to 30 m. Black pepper is growing as a woody climber around the clove trees. The second layer consists of cinnamon trees with a canopy depth ranging from 8 to 17 m. The use of other trees besides clove and cinnamon was not observed. The third layer comprises mainly cardamom with a canopy depth of 1 to 2 m. This layer covers more than 80% of the field plot. Other vegetation integrated in the patches of cardamom are shrubs such as *Lantana camara, Vernonia* spp.*, Clidemia hirta, Stachytarpheta jamaicensis* and herbs (*Justicia* spp., *Polygala* spp., *Impatiens* spp., ferns, *Commelina* spp., *Mimosa pudica*, *Senencio* spp., *Ipomea batata*, *Rubus rosifolis*, *Afromomum corrorima*, and *Afromomum melegueta*). The incorporation of animals in the system is rare. Management includes tending to the trees and minimal weeding.

As the soils are very strongly leached due to the Precambrian parent material and very high rainfall, coffee and arable crops in general do very poorly. Hence, farmers grow mainly spices requiring warm and humid conditions for cash and rely on market purchases for food.

3.2 Composition and diversity of tree species in the study landscapes

3.2.1 Tree species composition, occurrence, and diversity

A total of 73 tree species native and non-native were identified across the four study areas (Table 2; Supplementary Figure S2). The most common native tree species identified were *Albizia schimperiana, Maragaritaria discoidea*, *Cordia africana (abyssinica), Ficus Vallis-Choudae, Croton macrostachyus/megalocarpus, Olea capensis*, *Markhamia lutea*, and *Telfairia pedata*. The most common non-native tree species were *Syzygium aromaticum* and *Cinnamomum zeylanicum* (dominant in Mixed spices agroforestry) and *Grevillea robusta*, *Persea americana, Psidium guajava, Mangifera indica*, *Eucalyptus* spp., *Pinus patula*, *cypress* (*Cupressus* spp), and *Acacia mearnsii* dominant in the Miraba and Ginger agroforestry.

Our results show that Kihamba agroforestry has more native tree species per plot, i.e., 2.77 ± 0.28 as compared to Ginger agroforestry 1.83 ± 0.33. Miraba and Mixed spices agroforestry do not have native species in farm plots (Tables 2, 4; Supplementary Figure S2). We found a similar pattern for non-native tree species where Kihamba agroforestry scored a mean of 2.54 ± 0.18 followed by Ginger agroforestry 2.22 ± 0.33 and Miraba agroforestry 1.95 ± 0.17 (Table 4). Mixed spices agroforestry only has clove trees in the upper canopy (*Syzygium aromaticum*) and cinnamon trees in the second layer (*Cinnamon zeylanicum*). Kihamba and Ginger agroforestry have the highest Shannon–Weaver Index diversity, with scores of 2.82 and 3.03, respectively, while that of Miraba is 1.66 and of Mixed spices agroforestry is 1.45 (Table 4).

3.2.2 Tree species similarity between agroforestry systems

Similarities and dissimilarities of tree species communities in the studied systems are presented in Tables 3, 5, Supplementary Table S2, and Supplementary Figure S1. The two agroforestry systems with native trees (i.e., Kihamba and Ginger agroforestry) were investigated for tree species similarity and dissimilarity (Sorenson's coefficient indices; Sébastien, 2010; International Coffee Organization, 2018; Ichinose et al., 2020). A total of 12 tree species (Tables 3, 5; Supplementary Table S1) common in both systems were identified for coefficient index analysis. According to Sorenson's coefficient, Kihamba and Ginger agroforestry do not have much overlap or similarity in their tree species composition (Sorenson's Coefficient (CC) = 0.38) (Supplementary Table S2).

3.3 Tree species and ecosystem services

The contribution of native and non-native tree species to ES differed among the studied areas (as shown in Tables 3, 5 and Figure 5). Native tree species are perceived as important for food and fodder very commonly in Kihamba (80% of native tree species) and Ginger agroforestry (75%). Shade also was an important service of native trees in those systems (70%, as compared to ≤20% for non-native species). Non-native trees are also used for food or fodder but much less for shade. In the Usambara, no native trees were encountered. Non-native trees were mostly valued as important for fuel and timber in Miraba and food (clove and cinnamon; data not shown) in Mixed Spices agroforestry (Figure 5).

When split according to species (Tables 3, 5; Figure 6; Supplementary Figure S3), it becomes evident that farmers have different requirements in different systems and use different trees to meet them. Moreover, a tree can have a different function in different agroforestry systems. In Kihamba, the largest share of trees was reported to be planted for food and fodder, and they

TABLE 3 Non-native tree species in indigenous agroforestry systems and the farmers' reported provisioning ecosystem services.

	Reported ecosystem service			
Non-native tree species	Kihamba	Ginger agroforestry	Miraba	Mixed spices
Acacia mearnsii	–	–	Fuel, timber	–
***Artocarpus heterophyllus*	Food	–	–	–
Annona senegalensis		Food		
***Artocarpus heterophyllus*	–	Food, fodder	–	–
Calliandra calothyrsus	Fodder	–	–	–
Callistemon citrinus	Forage, Fuel	–	–	–
Calotropis procera	–	Shade, Fuelwood	–	–
Carica papaya L.	Food	–	–	–
Cedrela odorata	–	Timber	–	–
Cedrus libani	Timber	–	–	–
Cinnamon zeylanicum	–	Food	–	Food (spice)
Citrus limon	–	Food	–	–
Citrus sinensis	–	Food	–	–
Cupressus lusitanica	–	–	Fuel, timber	–
***Eriobotrya japonica*	Food, fodder,shade	Food	Food	–
Eucalyptus spp	–	–	Timber	–
Eucalyptus camadulensis	Timber	–	–	–
Eucalyptus saligna	–	Timber	–	–
***Grevillea robusta*	Fuelwood, timber, shade	Fuel, timber	Fuel, timber soil conservation, shade	–
Leucaena leucocephala	Fodder	–	–	–
Malus domestica			Food	–
***Mangifera indica*	Food	Food	Food	–
Passiflora edulis	Food, fodder	–	–	–
***Persea americana*	Food, fodder	Food/fodder	–	–
Pinus patula	Timber	–	Fuel, soil conservation, shade, timber	–
Prunus persica	Food	Food, shade	–	–
Psidium cattleianum	–	Food	–	–
***Psidium guajava*	Food	Food, fodder	–	–
Sechium edule (Jacq.)	Food, fodder	–	–	–
Syzygium aromaticum		–	–	Food (spice)

** Denotes tree species common in both Kihamba and Ginger agroforestry. "-" denotes not encountered.

belonged to a wide range of species (with *Margaritaria* and *Rauvolfia* being the main native species, and avocado as an important non-native). The second largest group was planted for shade, most of them being natives (*Albizia, Cordia, Croton*, and a variety of other species). *Albizia* is also important for fuel in Kihamba, and *Grevillea* is found to be an important non-native used for fuel and timber in the system. In Ginger agroforestry, trees were mainly planted for food and fodder (with fruit trees having the largest share) and shade (*Albizia* and a range of other native species). Few trees were encountered in Miraba, and fuel and timber were the most sought-after ES, with large shares for *Grevillea, Acacia,* and pine. Fruit trees are relatively rare (loquat, apple, and mango). *Grevillea* and pine are used for shade although farmers in the West Usambara use the term 'shade' also to denote soil and water conservation.

A PERMANOVA (Table 6) and NMDS ordination plot of Bray–Curtis community dissimilarities (Figure 7) confirmed that there is a significant difference between the identified tree species in the studied systems and the smallholder farmers reported most important ES ($p < 0.001$) across the study areas. This implies that the identified tree species have a most significant influence on the smallholder farmers who reported multiple ES (food/fodder, fuelwood, timber, and shade) at p of <0.05 across the studied agroforestry systems.

TABLE 4 Diversity, evenness, and equitability of tree species (native and non-native) in the indigenous agroforestry systems.

System	Tree species	Total number of species encountered	Average number of species per plot	s.e.	*n*	Shannon index (H′)	Equitability
Kihamba	Native	16	2.77	0.28	35	2.82	0.81
	Non-native	16	2.54	0.18			
Ginger	Native	15	1.83	0.33	18	3.03	0.89
	Non-native	16	2.22	0.33			
Miraba	Native	–	0.00	–	20	1.66	0.80
	Non-native	8	1.95	0.17			
Mixed spices	Native	–	0.00	–	9	1.45	0.70
	Non-native	2	2	–			

s.e = standard error, n = number of observed plots. "-" denotes not encountered.

TABLE 5 Native tree species in the agroforestry systems and their reported provisioning ecosystem services (no native tree species were identified in Miraba and Mixed spices).

Native tree species	Reported ecosystem services	
	Kihamba	Ginger agroforestry
***Albizia schimperiana*	Fodder, fuelwood, shade	Fodder, fuelwood, shade
***Bridelia micrantha*	Fodder	Shade
***Cordia africana*	Food, fodder, fuelwood, shade	Shade
Commiphora zimmermannii	Fodder, shade	–
Croton macrostachyus	Food, fodder, shade	–
Croton megalocarpus	–	Shade
Cussonia holstii	Fodder	–
***Ficus Vallis-Choudae*	Shade	Shade
Ficus natalensis	Shade	
–		Food, fodder
Lannea schweinfurthii	Food, fodder, shade	–
Maragaritaria discoidea	Food, fodder, fuelwood, shade	–
***Markhamia lutea*	Timber	Food, fodder, shade
–	–	Food, fodder
–	–	Food, fodder
Mitragyna rubrostipulata	Food (medicinal)	–
Newtonia buchananii	–	Fodder, fuelwood, shade
Olea capensis	Food, fodder	
Pterocarpus angolensis		Timber, shade
Rauvolfia caffra	Food, fodder, shade	–
Syzigium guineense	–	Food, fodder, shade
Tarenna pavettoides	–	Food (medicinal)
***Telfairia pedata*	Food, fodder, shade	Food, fodder
Trichilia dregeana	–	Fuelwood, timber
Vangueria madagascariensis	Food, fodder	–

"-" denotes not encountered.

Moreover, our results generated by multipatt command from indicator species analysis (Supplementary Table S6) show statistically significant native tree species abundance ($p < 0.04$) for *Maragaritaria discoidea* and ($p < 0.02$) for *Albizia schimperiana* associated with Kihamba. These tree species have high relative abundance in the provision of food/fodder and shade. Locally native tree species *Mguthuru* ($p < 0.03$) and *Newtonia buchananii* ($p < 0.05$) were found statistically significant associated with Ginger agroforestry (Supplementary Table S7).

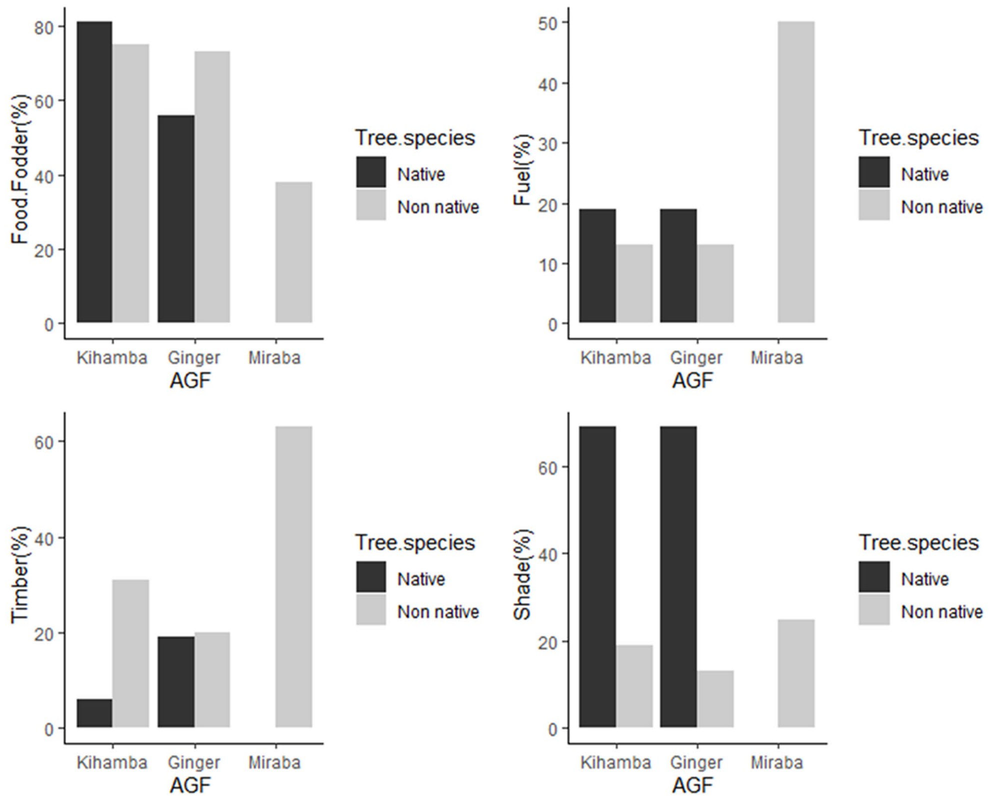

FIGURE 5
Percentage contribution of native and non-native tree species in smallholder systems reported as most important for provisioning of the ecosystem services food or fodder, fuel, timber, and shade. Mixed spices agroforestry is omitted as the trees in this system were exclusively used for the production of spices.

4 Discussion

4.1 Structure and species composition of the indigenous agroforestry systems in the studied areas

The agroforestry systems studied, i.e., Kihamba, Ginger agroforestry, and Miraba and Mixed spices agroforestry, are unique to Tanzania and East Africa (O'kting'ati and Mongi, 1986; Rugalema et al., 1994; Hemp and Hemp, 2008; Namwata et al., 2012; Kinyili et al., 2019). Although all studied systems are multi-layered with three or four vertical layers, our study shows that they have notable differences in their salient features mainly because of the unique climate, landscape setting, soils, historical background, habitat, and species adaptation that exists in this region (Table 1; Figures 3, 4; Namwata et al., 2012). Therefore, understanding the salient features of these systems including arrangements and patterns in space and the composition of their components will be of paramount importance in conserving these important agricultural heritage systems (cf. Charles, 2015; Reetsch et al., 2020a,b).

Kihamba homegardens have existed for over 800 years and most closely mimic a tropical montane forest, often containing mature tree species with a canopy layer height of more than 40 m and a large variety of native and non-native species (Figure 3; Tables 2, 4). This layout offers optimal growing conditions for coffee and banana on the volcanic soils of Kilimanjaro, while an important integration of cattle in the homegardens keeps soil fertility up to par for those demanding crops. Nevertheless, a crash in coffee prices has induced a shift in tree species toward other cash crops, notably avocado. The Ginger agroforestry in the South Pare mountains has a cultural link to the Kihamba on Kilimanjaro (Kitalyi et al., 2013; Ndaki, 2014), but as coffee and banana income declined even faster on the poorer, Precambrian soils, a boom of pests and coffee diseases motivated farmers to switch to growing ginger (70% of production in Tanzania) and sugarcane (Ndaki, 2014). As ginger is a root crop requiring a dappled shade, farmers kept the shade trees that are also common in Kihamba, but with a fewer dense canopy lowering light and root competition (Table 4; Figure 3). The introduction of ginger, hence, escalated the deforestation of the native tree species in the Pare mountains (Ndaki, 2014; Mmasa and Mhagama, 2017), while the lower nutrient requirements also contributed to a reduction in heads of cattle and fodder trees. This concurs with the increasing importance of non-native trees, mainly fruits, in the overstory layer (Figure 5; Table 3), consistent with earlier findings of Nath et al. (2016).

In Miraba, the culture of maize and vegetables requires ample sunlight, so farmers only plant scattered trees among the Miraba hedge lines (Figure 4). There was no culture of traditional homegardens as in Kilimanjaro and Pare, yet the use of Miraba (hedges) around fields was traditionally practiced mainly by women (Msita et al., 2010, 2012). The use of trees native to the area in farming was not part of the tradition. Historically, the Usambara mountains were covered by native forest tree species, such as *Albizia gummifera,*

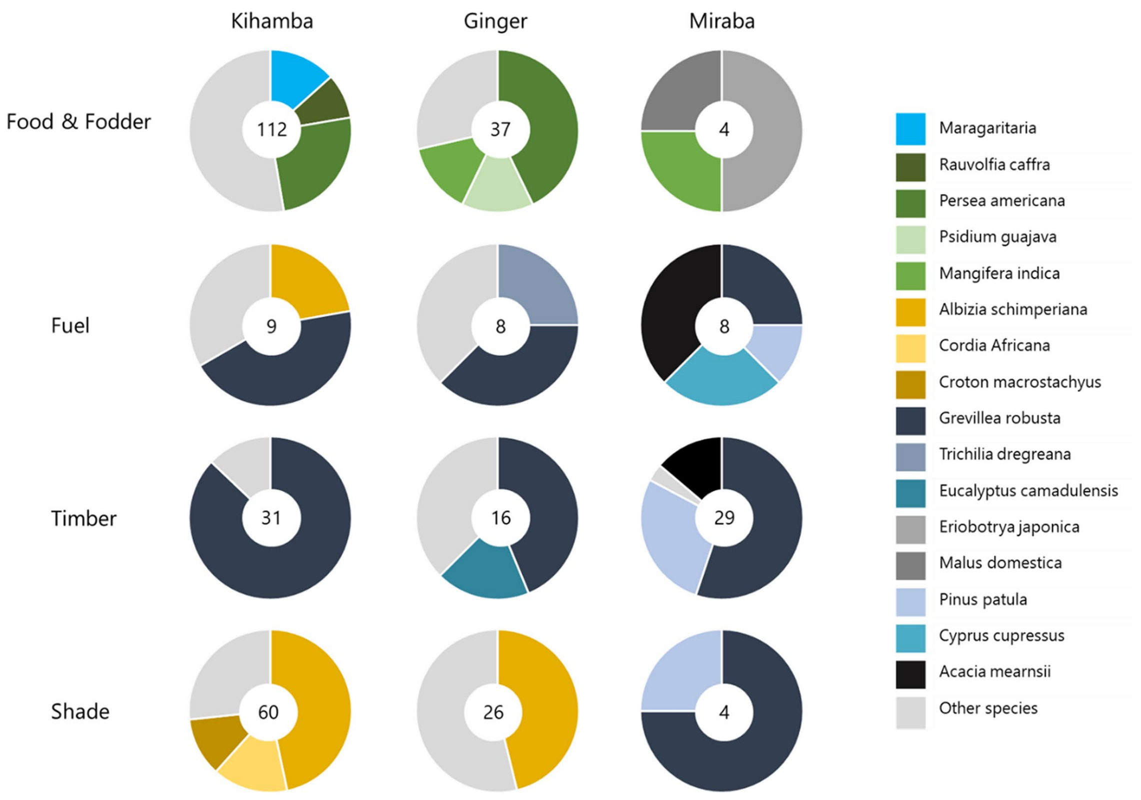

FIGURE 6
Use of species for different ecosystem services across the different agroforestry systems. Numbers denote the number of trees encountered in the plots that farmers indicated as planted primarily for that ecosystem service, and charts denote the relative share of tree species. Species with a low share were grouped under 'other species.' Mixed spices is omitted as the overstory only consists of clove.

TABLE 6 Permutational multivariate analysis of variance (PERMANOVA) of multi-layer agroforestry systems tree species on the smallholder farmers reported ecosystem services.

	Df	Sums of sqs	Mean sqs	F.Model	R^2	Pr(>F)	
Tree spp. AGF	3	1.6034	0.53446	3.0803	0.42913	0.001	***
Area ES	2	1.0919	0.54594	3.1465	0.29224	0.003	**
Residuals	6	1.0411	0.17351		0.27863		
Total	11	3.7363			1		

Significance codes: 0 '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1; '' 1.
AFG, agroforestry system; ES, ecosystem service.

Prunus africana, Catha edulis, Ocotea usambarensis, Podocarpus usambarensis, Parinari excelsa, and *Milicia excelsa* (Msuya et al., 2008). However, much of the forest tree species were logged for timber before the logging ban of 1984 (MNRT, 2001; FAO, 2005). Increasing population densities expanded community activities, i.e., cultivation of maize, beans, and Irish potatoes on slopes and vegetables on valley bottoms. The intensification in land use led to severe soil erosion on the mountain slopes and flash floods in the valley bottoms (Haruyama and Toko, 2005; Msuya et al., 2008). Due to these challenges, Miraba was promoted as a soil conservation measure. Other interventions in the landscape, for example, the Gesellschaft für Technische Zusammenarbeit (GTZ) project on Soil Erosion Control and Agroforestry (SECAP) in collaboration with other institutions including the Tanzania Forestry Research Institute (TAFORI), introduced non-native tree species, such as *Grevillea,* pine, and eucalyptus for curbing soil erosion and to reduce logging (Johansson, 2001; Msuya et al., 2008). Hence, these species remain important in the landscape (Table 3; Figure 6).

East Usambara receives very high amounts of rain from the Indian Ocean. Combined with the Precambrian, easily leachable soils, it makes it difficult to get good yields of arable crops, banana, or coffee. As the region has cultural ties to Zanzibar, Madagascar, and India, a system of spice crops that thrive in high humidity and on well-draining soils has been practiced here for over 50 years (Figure 3; Hall et al., 2011). This type of agroforestry starts with the thinning of canopy trees to create 50% shade and the complete clearance of the lower strata of a once natural forest (Reyes et al., 2005; Hall et al., 2011). Those authors noticed an absence of young native tree species in two-thirds of the active agroforest sites, questioning the ability of the Mixed spices agroforestry to contribute to the conservation goals

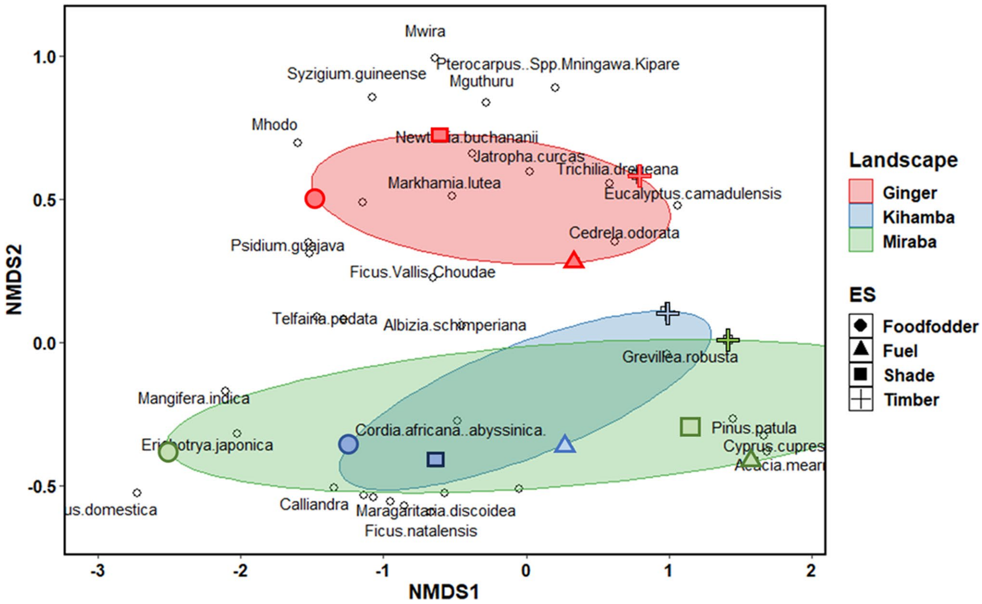

FIGURE 7
Represent non-metric multidimensional scaling (NMDS) ordination plot of Bray–Curtis community dissimilarities index showing homogeneity of the variances and relationship between tree species community distribution and the offered multiple provisioning ES in different mountainous AGF.

of the East Usambara Mountains (Reyes et al., 2010; Hall et al., 2011). During our field campaign in 2021, native trees were absent from the canopy. Mature clove trees are most productive in full sunlight, and their conical–cylindrical shape allows ample sunlight for the cinnamon trees below. Land scarcity may push to a further clearing of the original canopy to prevent competition for light and space with clove and cinnamon trees. Black pepper and cardamom require partial to full shade underneath the trees, and pepper uses the clove trees for support.

4.2 Provisioning ecosystem services required by farmers in the different systems

Consistent with the farming strategies described above, farmers have different ES requirements for trees in the different systems (Tables 3, 5), providing a more diversified image as compared to earlier studies stressing the importance of on-farm tree resources for the provision of food, fodder, shade, timber, and fuel (Munishi et al., 2008; Charles, 2015; Wagner et al., 2019).

Moreover, our analysis shows that tree species are used in different ways in the different agroforestry systems (Figures 6, 7).

The identification of dominant native tree species, such as *Albizia schimperiana*, *Maragaritaria discoidea*, *Rauvolfia caffra*, and *Cordia africana*, in the studied agroforestry systems holds significant implications for ecosystem services provisioning. These trees play a pivotal role in the sustainability and multifunctionality of the agroecosystems in northeastern Tanzania. Notably, they serve as crucial shade providers for coffee cultivation, contribute to fodder production, serve as a source of fuelwood, and in some instances, are employed for medicinal purposes. As such, native species are mainly valued in systems requiring shading of coffee, banana, or ginger, and in systems with an important cattle component, notably in Kihamba (Banzi and Kalisa, 2021). In Ginger agroforestry, *Albizia schimperiana* remains as a shade tree but fodder trees are being replaced by fruits (Figure 6).

The findings of this study align with prior research in the same study area, reinforcing the importance of *Albizia schimperiana* as a primary choice for shading coffee in both smallholder farms and large-scale commercial coffee plantations (Hundera, 2016). Findings in our study revealed that native species in the Kihamba remain important for communities in accessing ES, such as food, fodder, fuel, and timber, and in providing shade for the production of coffee, banana, firewood, roots, and tuber crops as well as vegetables (Figure 5; Table 5). In this system, farmers have accumulated wide indigenous knowledge and use a wide range of trees and shrubs (Figure 6; Akinnifesi et al., 2008; Hemp and Hemp, 2008; Reetsch et al., 2020a,b).

However, we demonstrated that the proportions of non-native tree species are becoming competitive with native tree species in the studied areas, and native species are not or no longer used in farming in the Usambara Mountains. For example, *Grevillea robusta*, *Persea americana*, and *Eucalyptus camadulensis* have been introduced for the timber market and have replaced part of the native trees used for fuel and timber in Kihamba and Ginger agroforestry (Table 3; Figures 5, 6). Fruit trees are replacing native food and fodder trees most notably not only in Ginger agroforestry but also in Kihamba. In systems with no shade requirements (Miraba) or where native tree species would compete with tree crops (Mixed spices agroforestry), native trees are now absent from fields and homegardens.

4.3 Prospects for conservation

The tree component of agroforestry systems is important not only for provisioning services but also for supporting, regulating, and cultural ES important for conservation and ecosystem resilience (Soini, 2005; Graham et al., 2022). Mature, native trees in Kihamba have been reported as important for biodiversity conservation and carbon sequestration (Fernandes et al., 1984; Gupta et al., 2009). The taller canopy provides a diverse range of habitats and niches, supporting a greater variety of flora and fauna, contributing to overall biodiversity in the agroforestry system (Hemp, 2006). The Kihamba native tree layer has, moreover, been shown efficient in controlling landslides, in reducing soil erosion, in improving soil fertility, and in protecting sources of water for local and downstream users (Kitalyi and Soini, 2004; Hemp and Hemp, 2008; Mbeyale, 2010; Santoro et al., 2020; Reetsch et al., 2020a,b; Banzi and Kalisa, 2021; Mbeyale and Mcharo, 2022). In the North Pare Mountains, agroforestry tree species help to improve the resilience of smallholder farmers against environmental extremes by modifying temperatures (Charles, 2015). The absence of native tree species has, moreover, changed the outlook of the landscapes in terms of their pristineness, cultural history, and land use/cover arrangements. Restoration efforts and re-introduction of native species have, thus, been proposed to improve the resilience of the studied systems and are advocated as an avenue to minimize conflicts and encroachment into the protected areas (Johansson, 2001; Kueffer et al., 2013; López et al., 2017).

Over the past 100 years, farming systems in the northeastern Mountains of Tanzania have undergone several transformations due to colonial and post-colonial policies, land scarcity, migration of younger generations to urban areas, crop pests and diseases, and collapse in coffee prices (Chuhila, 2016; von Hellermann, 2016). The results of our study corroborate the importance of livelihood strategies on the tree component of agroforestry systems (Figures 3–7), corroborating the statement that these challenges have led the smallholder farmers in the area to diversify their sources of income to accommodate external changes and market dynamics (Namwata et al., 2012). The majority of smallholder farmers have adopted the introduced non-native tree species, sometimes for conservation value but more so for their economic benefits (von Hellermann, 2016; Figures 5, 6). Hence, differences in the context of smallholder farming conditions and ES requirements, as evidenced in our study, should be taken into consideration for restoration efforts to be successful.

von Hellermann (2016) stressed the importance of an increased sale of coffee for agroforestry during the 1940s. Our study corroborates that shade ES required for coffee farming promotes the use native tree species (Figure 5) and supports the hypothesis that a collapse in coffee prices since has led to a gradual abandonment of the coffee crop and diversification of crop production in Kilimanjaro and Pare (Ndaki, 2014), leading to a deforestation of the native tree species (Ndaki, 2014; Mmasa and Mhagama, 2017; Table 4). If native trees are to be restored in this region, additional research and supporting measures are needed to help farmers build alternative value chains for products that can benefit from the ES from native species, such as the sale of milk or honey from (stingless) bees (Eersels, 2022; Tersago, 2022).

In the East Usambara mountains, protecting habitat for endemic species is one of the most important conservation objectives (Burgess et al., 2007; Hall et al., 2011). In Mixed spices agroforestry, the strata of a once natural forest (Reyes et al., 2005; Hall et al., 2011) have now completely disappeared (Table 4). Several authors, therefore, question the contribution of Mixed spices agroforestry to conservation goals (Reyes et al., 2010; Hall et al., 2011). Although such a tree-covered agricultural system may provide additional ecological services compared to sun-grown agriculture, a lower compositional and structural diversity will affect the ES not related to food production as compared to natural forests. Furthermore, a more profitable cardamom market could be beneficial to local farmers, which may encourage agroforestry establishment in currently deforested areas but could also lead to the expansion of cultivation into protected areas (Reyes et al., 2010). Some previous studies suggest that sustainable cultivation of spice is possible (Kumar and Nair, 2004; Reyes et al., 2006; Swallow et al., 2006) and that some farmers are already adopting ecologically sound intensification practices in homegardens (Reyes, 2008; Reyes et al., 2010). Therefore, any efforts to encourage integrated Mixed spices agroforestry with other native agroforestry tree species should be explored. Nevertheless, as all farms in our study do not have productive ES requirements for trees other than clove and cinnamon (Tables 3, 5), these efforts will not be straightforward to realize for farmers from a livelihood perspective without flanking measures. The protection of native vegetation in forest reserves, therefore, also remains an urgent priority.

The role of policy and knowledge bias in agroforestry tree composition has been highlighted by several authors. Worboys (1979) and Sheridan (2001) mentioned the role of policy and mass promotion by government regimes with a motive to produce timber for export and also restore previously cleared forests. Interventions to control erosion and reduce logging introduced non-native species, such as *Grevillea,* pine, and eucalyptus, as these are well studied in the international literature on soil and water conservation, as compared to species native to the Usambara (Johansson, 2001; Msuya et al., 2008). Policies to restore the native tree cover can, therefore, only be successful if underpinned by a better knowledge of local species and their potential to be aligned with the diverse ES needs of local communities (Figures 5–7). Kihamba agroforestry can serve as an inspiration as it shows a kind of resilience in terms of available native tree species that are the remnants of the forest tree species (Table 5; Figure 6) and has been shown very efficient in the provisioning of ES for conservation purposes (Hemp and Hemp, 2008; Reetsch et al., 2020a,b). The fact that Kihamba farmers still use native tree species for ES that are also required in systems without native species (Figures 6, 7) indicates potential for the exchange of indigenous knowledge between distant communities as well as for driving scientific research toward the potential of these trees.

5 Conclusion

Our study has highlighted the differences in salient features between the agroforestry systems of Mt. Kilimanjaro (Kihamba), the South Pare Mountains (Ginger agroforestry), and the West and East Usambara (Miraba and Mixed spices agroforestry, respectively). All systems are multi-layered with an important tree component, but they considerably differ in terms of structure, tree species composition (both native and non-native), and diversity. Our findings reported provisioning ES corroborates our hypothesis that the choice of overstory tree species is closely linked to farmers' ES needs, livelihood strategies, and the salient features of each system. The Kihamba system has retained higher proportions of native trees and uses more native tree species for provisioning ES as compared to the other systems. The higher proportions of non-native tree species in Miraba and Mixed spices agroforestry are dictated by economical needs for timber, fuel, and sun-requiring cash crops. Policies to increase resilience and restore the native tree species cover, therefore, can only be successful based on the knowledge of native species, their traits, and ES potential. Furthermore, they should balance conservation and livelihood, acknowledge the complex mix of pressures on farmers' livelihoods, and propose measures tailored to the areas' salient features and specific challenges.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

OK, KV, and K-HF: conceptualization and methodology. OK, DK, KV, and K-HF: investigation. OK, DK, KV, ED, and K-HF: validation, data curation, reviewing, and editing. OK: formal analysis and writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2023.1082864/full#supplementary-material

SUPPLEMENTARY FIGURE S1
Schematic example showing tree species distribution and evenness in AGF farm plots (Similarities and dissimilarities) (Allison, 2019).

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