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ShadeTreeAdvice methodology: Guiding tree-species selection using local knowledge

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Abstract

1. Selection of shade tree species for agroforestry systems must take the complexity of these systems into account. Tree species selection should maximize the provision of ecosystem services while minimizing disservices. Selected species must be adapted to local agroecological conditions and cater to farmers' needs, while considering their preferences and constraints.
2. The ShadeTreeAdvice methodology was developed to support said selection process using farmers' local ecological knowledge. It provides the steps to rapidly identify tree species and evaluate their impacts on a range of locally important ecosystem services. Results are uploaded to a decision support tool to tailor tree species recommendations to individual farmers' needs (www.shadetreeadvice.org). During the 5 year timeframe between 2016 and 2020, eight studies following this methodology were conducted in various coffee and cocoa growing regions across Africa, Asia and Central America.
3. This article looks back at these studies to synthesize their findings and evaluate the methodology. We identified similarities in the use of tree species across different study areas, notably regarding leguminous and fruit tree species. We showed that the method was efficient to evaluate tree species' impacts on soil and climate regulation, crop production, and economic benefits. It was less efficient for evaluating impacts related to incidence of pests and diseases, often associated with knowledge gaps. The method also successfully allowed investigating the links between LEK and socio-economic groups or environmental factors.
4. Furthermore, we suggest a series of improvements in the methodology for future studies. These improvements include (i) broadening the scope of studies beyond tree species provision of ecosystem services to include tree species impact on farming practices; (ii) allowing the comparison of tree performances in

agroforestry systems versus in full sun; (iii) providing a clear pathway for validation of the results; (iv) using tree species' functional traits to generalize the results.

KEYWORDS
agroforestry, decision support tool, ecosystem services, farming practices, local ecological knowledge, shade tree species, trade-offs

1 | INTRODUCTION

Multiple government, private sector and NGO driven initiatives promoting agroforestry practices in coffee and cocoa farming systems are emerging in tropical countries. These initiatives rely on a growing body of technical and science-based evidence showing that shade trees in farming systems can provide multiple benefits and contribute to sustainable agricultural models. These benefits may include enhanced income diversification and economic resilience (Jassogne et al., 2012; Jezeer et al., 2018), improved soil protection and nutrient cycling (Nijmeijer et al., 2019; Tully & Lawrence, 2012), and higher carbon sequestration and resilience to climate change (Guillemot et al., 2018; Nijmeijer et al., 2019). These benefits and the overall success of agroforestry systems are however contingent upon the selection of suitable shade tree species. Tree species must be adapted to local agro-ecological conditions, provide a positive balance between their impacts on ecosystem services (ES) and disservices (ED), fit farmers' preferences and cater to their needs (German et al., 2006). Selecting unsuitable shade tree species could on the other hand lead to higher incidence of certain pests and diseases (Bukomeko et al., 2018) or to increased competition with the main crops (Abdulai et al., 2018), resulting in loss of productivity followed by the removal of shade trees. Likewise, farmers will often remove or replace shade trees whose impacts mismatch their needs, for instance shade trees providing environmental benefits but little to no economic incentive (Nath et al., 2016). Shade tree species selection is thus a pivotal step in designing and promoting successful and long lasting agroforestry systems.

Most research and initiatives for shade tree promotion in farming systems have so far focused on a limited number of well-documented tree species (Hastings et al., 2020). These few tree species, albeit often successfully grown in small-scale pilot projects, cannot fit all the various social and ecological conditions needed for scaling up agroforestry practices beyond initial project sites, and thus did not lead to widespread dissemination of promoted agroforestry systems (Coe et al., 2014). In response, a growing number of studies started advocating the use of participatory methods and increased reliance on farmers' local ecological knowledge (LEK). LEK refers to a body of knowledge, practice and belief held by stakeholders, gained through personal observations and interactions with their local ecosystem (Charnley et al., 2007; Olsson & Folke, 2001). One reason behind the increased reliance on LEK is its complementarity with existing databases and academic knowledge, allowing researchers to screen through large pools of native tree species to identify locally suitable ones (Smith Dumont et al., 2019; Uprety et al., 2012). In addition, the use of participatory methods results in higher levels of engagements from local stakeholders, better fits between agroforestry system designs and farmers' needs, and therefore increased adoption rates (Smith Dumont et al., 2019). Therefore, the use of participatory methods and reliance on LEK to develop locally adapted tree species recommendations is gaining popularity in conservation studies (Charnley et al., 2007; de Albuquerque et al., 2009), forest restoration studies (Chechina & Hamann, 2015; Fremout et al., 2021) and agroforestry studies (Smith Dumont et al., 2014, 2018). Furthermore, a few digital tools based on LEK have emerged to guide tree species selection (Fremout et al., 2022; Reubens et al., 2011). Yet, LEK studies to guide tree species selection often lack comparability and face methodological challenges to collect LEK (Barber & Jackson, 2015; Thomas et al., 2007), analyse it (Charnley et al., 2007; Gosling & Reith, 2020) and link it to farming practices and all the way to practical recommendations (Uprety et al., 2012; Valencia et al., 2015). There is therefore the need to develop and test robust methodologies to document farmers' LEK with a view to recommending shade tree species tailored to local needs.

Methodologies based on qualitative approaches are well adapted to investigate in-depth knowledge, especially when this knowledge is held only by a few stakeholders, and to map complex interaction networks. Tools such as the Agroecological Knowledge Toolkit (AKT) are specifically designed to generate causal diagrams (Sinclair & Walker, 1998), useful to disentangle the complex network of interactions within agroforestry systems. Participatory mapping (Tusznio et al., 2020) and narrative field walks (Jerneck & Olsson, 2013; Suárez et al., 2012) are other increasingly popular methods to document farmers' qualitative knowledge. The resulting in-depth understanding can in turn provide knowledge unknown to the academic sphere, such as the classification of shade tree species into “fresh” and “hot” categories documented by Cerdán et al. (2012). It can help identifying and designing farming practices to solve complex issues, such as that of pest regulation (Liebig et al., 2016). This is especially the case in areas where farmers benefit from long standing farming systems and the associated traditional ecological knowledge (Cerdán et al., 2012; Charnley et al., 2007). As opposed to areas in rapid mutations, such as coffee areas found in southeast Asia (Nguyen et al., 2020; Rigal et al., 2018) where local ecological knowledge is rapidly evolving based on farmers' recent experiences, and cannot be called traditional knowledge (Charnley et al., 2007). Finally, qualitative approaches also allow the identification of constraints to the dissemination of results and adoption of practices, such as the lack of access to germplasm (Smith Dumont et al., 2019).

Quantitative approaches in ethnobotany offer another way to study LEK. Numerous indices have been developed to evaluate species attributes from local knowledge such as species' cultural importance or usefulness. Such indices are well suited for quantitative comparisons between species using statistical tools, and identification of species with high potential for recommendations (de Albuquerque et al., 2009). For instance, Suárez et al. (2012) derived quantitative indices on tree species' usefulness, scarcity and importance for wildlife from interviews to help select tree species for reforestation in Mexico. Fremout et al. (2021) used local knowledge to quantify tree species' usefulness (cultural importance index) and threat status (salience index) for reforestation in the Andes. Brandt et al. (2013) calculated the same indices to evaluate tree species in agroforestry systems in Bolivia. These quantitative methods prove to be especially efficient when the investigated knowledge is shared among large groups of respondents, allowing for statistical approaches, but become of limited use when only few respondents hold the knowledge. Furthermore, these methods are powerful in describing attributes or performances, but not in explaining or investigating causal relationships in complex biotic networks. Qualitative and quantitative approaches thus provide complementary results and can benefit from being combined.

The ShadeTreeAdvice methodology was developed and intended as a standardized methodology to document farmers' knowledge on shade tree species and their provision of ecosystem services (van der Wolf et al., 2016). It partakes in a quantitative approach through the development of alternative indices for tree species' performances. In this methodology, the documentation of farmer's knowledge takes place through rankings of tree species they are most familiar with. Rankings are then converted into scores representing the performances of each shade tree species and allowing their comparisons (Turner et al., 2020; Turner & Firth, 2012). The methodology was first developed and tested in East Africa (Gram et al., 2017) before being replicated and adapted in West Africa, Southeast Asia and Central America. Importantly, the methodology goes all the way to practical recommendations through an online decision-support tool (www.shadetreeadvice.org). Results are uploaded to the online tool and translated into applicable information for farmers and extension agents, guiding the selection of shade tree species tailored to local contexts and individual's preferences. In recent years, several entities spanning development agencies, local governments and private companies expressed their interest in the tool to support the design of local agroforestry programs (personal communications), confirming the relevance of the methodology and of the associated online tool.

The ShadeTreeAdvice methodology was applied in eight studies between 2016 and 2020, both in coffee and cocoa growing regions, and results were uploaded online. The article presents these eight ShadeTreeAdvice studies and synthesizes their findings, by nature context-specific, to draw general lessons about farmers' LEK and use of shade tree species. More specifically, this article (i) explores the similarities in shade tree species use and performances across study areas; (ii) investigates the importance of ES as drivers of agroforestry practices and identifies knowledge gaps associated to important ES; (iii) links LEK to socio-economic and environmental factors. Based on this synthesis, the article then points out the strengths and limitations of the current ShadeTreeAdvice methodology and suggests methodological improvements to deepen and broaden the research scope of future studies. Lastly, feedback from users of the decision-support tool are briefly presented along with avenues to improve the tool and expand its use.

2 | MATERIALS AND METHODS

2.1 | Presentation of ShadeTreeAdvice

The methodology was standardized by van der Wolf et al. (2016) with the following steps: (1) selection of the study area and farming systems; (2) identification of the most important ecosystem services for local farmers through participatory methods; (3) listing of local shade tree species through free listing by farmers and farm inventories; (4) stakeholder interviews and ranking of shade tree species for provision of locally important ES; (5) analysis of ranking data with Bradley-Terry analysis to estimate performances of tree species; (6) comparison of results with existing scientific knowledge. This methodology revolves around two central concepts: the emphasis given to local solutions to solve local challenges (steps 1 to 3) and the search for the right balance between efficiency of data collection and robustness/usefulness of results (steps 4 to 6).

Local ecological knowledge gathered with the ShadeTreeAdvice methodology feeds into a decision-support tool available at www.shadetreeadvice.org. The list of studies is displayed on a map and linked with the corresponding articles. In the tool tab, users can select their area, their crop and a set of ES that they consider a priority for their farming system. The tool combines the scores of shade tree species for the selected ES, and displays their rankings in a chart. This allows the user to screen through the list of shade tree species and identify those with high potential to meet specific needs.

2.2 | ShadeTreeAdvice studies

The present article reviews the results from studies conducted between 2016 and 2020 that follow the ShadeTreeAdvice methodology (Table 1). There were eight studies, spreading across three continents—four studies were carried out in Africa, three in Southeast Asia and one in Central America—and spanning three perennial crops—six studies related to Arabica coffee (*Coffea arabica*), one to Robusta coffee (*Coffea canephora var. robusta*) and one to cocoa (*Theobroma cacao*).

TABLE 1 list of the 8 studies conducted using the ShadeTreeAdvice methodology between 2016 and 2020

Country	Main crop	No. of farmers interviewed	No. of tree species ranked	Factors of LEK analysis	Reference
Ghana	Cocoa	110	27	Precipitation	Graefe et al. (2017)
Uganda (a)	Arabica coffee	301	20	Elevation, gender	Gram et al. (2017)
Laos	Arabica coffee	83	29	Gender, soil type	Lépine (2018)
China	Arabica coffee	124	30	Ethnicity, gender, farming system age and diversity	Rigal et al. (2018)
Uganda (b)	Robusta coffee	300	27	Precipitation	Bukomeko et al. (2019)
Tanzania	Arabica coffee	263	22	Affiliation to farmer groups, elevation, gender, farming system composition	Wagner et al. (2019)
Nicaragua	Arabica coffee	65	29	Gender, tree position in farm	Carpente (2020)
Vietnam	Arabica coffee	118	25	Ethnicity, gender, distance to road	Nguyen et al. (2020)

In these studies, the ShadeTreeAdvice methodology was not only used to gather knowledge on shade tree species and feed the decision support tool, but also to investigate site-specific research questions related to LEK and the use of shade tree species in local agroforestry systems. In particular, most studies investigated the link between shade tree performances and environmental factors (Table 1). In Ghana and Central Uganda, the authors compared the performances of shade tree species in areas of low and of high precipitation, and highlighted nuances in farmer selection and management of shade trees according to precipitation (Bukomeko et al., 2019; Graefe et al., 2017). On Mount Elgon in Uganda and on Mount Kilimanjaro in Tanzania, the authors investigated farmers' priorities and shade tree preferences across elevations (Gram et al., 2017; Wagner et al., 2019). And in the Bolaven Plateau in Laos, Lépine (2018) compared farmers' knowledge and priorities in areas of high and low soil fertility.

The methodology was also used to explore the link between LEK and farming practices or socio-economic factors (Table 1). In Nicaragua, Carpente (2020) investigated farmers' preferences and use of shade trees inside coffee plots versus on plot edges, and compared perceptions of tree species between gender. On Mount Kilimanjaro, Wagner et al. (2019) compared farmers' priorities and knowledge on trees with the actual tree species composition of their farm, with farmers' affiliation to farmer groups and between gender. In Vietnam, Nguyen et al. (2020) investigated farmers' tree species preferences according to gender, ethnicity, their distance to road and access to market. And in Yunnan Province in China, Rigal et al. (2018) researched the emergence and evolution of LEK on shade trees alongside the emergence of large-scale agroforestry landscapes and compared perceptions of tree species between gender, ethnicity.

In the rest of the article, results specific to shade tree species and their provision of ES will only be drawn from the six ShadeTreeAdvice studies focusing on Arabica coffee. This will ease comparison between study sites with similar farming systems. General experiences regarding the methodology, its use and limitations will be drawn from the eight ShadeTreeAdvice studies, including the two studies on Robusta coffee and cocoa.

2.3 | Shade tree species and their perceived performances

The list of tree species documented across the six ShadeTreeAdvice studies on Arabica coffee was compiled to identify those most commonly used in coffee agroforestry systems in the study areas. Trees were categorized by species, families and classified as either “fruit trees”, “trees for other products (timber, firewood and fodder)” or “trees for provision of ecosystem services”, according to their main benefit as defined by farmers. Best performing trees were identified in all study sites based on their scores for three categories of ES listed below, and compared to draw general conclusions between tree species or families, tree attributes and farmers' perceptions. The three categories of ES selected for this analysis were ES related to soil regulation (the category of ES ranked in most studies), a second focus on ES related to coffee production (the main economic pillar of coffee farming systems), and a third focus on fruit production (a provisioning service especially important for smallholder farmers).

2.4 | Ecosystem services and knowledge gaps

The list of ES identified as locally important by farmers and documented across the six ShadeTreeAdvice studies on Arabica coffee was compiled. ES were classified into services related to coffee production (coffee yield and quality), microclimate regulation (protection from cold and heat), soil regulation (soil fertility, soil moisture, root competition, litter provision, erosion control), weed control, pests and diseases control, tree products for income generation and/or self-consumption (timber, fuelwood, and fodder on the one hand, fruit as a separate category) and enhancement of biodiversity. In four studies, shade tree species were also ranked for their attributes (suitability of shade provision, tree growth rate and tree adaptation to local growing conditions) and for their impacts on farming practices (need and ease of pruning, impact on fertilizers needs for coffee/cocoa). ES, tree attributes and farming practices included in most studies across the six studies on Arabica coffee were identified as both locally most relevant to farmers and easily ranked by them. The services, attributes and practices with few rankings were identified as less relevant to farmers, while those pointed out by authors as difficult to rank by farmers were linked to knowledge gaps.

Knowledge gaps were also identified through pairwise comparisons of tree species' scores. Indeed, ES where tree species' scores are most distinct from one another and where standard errors are the smallest reflect high consistency in farmers' rankings. Whereas ES where scores are similar and standard errors are the highest reflected disagreements among farmer rankings, therefore hinting at knowledge gaps. For each study site and ES, the percentage of significantly different scores were calculated using pairwise comparisons of tree species' scores with the Wald test. These percentages were averaged across the new classification of ES listed above, providing an indicator of depth and consistency of farmers' perceptions of tree species.

2.5 | Linking LEK to socio-economic groups and environmental factors

All studies investigated specific aspects of the relationship between farmers' priorities, their perceptions and/or their farming practices between various socio-economic groups and along environmental gradients. To do so, authors attempted various types of comparisons and correlations between locally important ES, tree species rankings and farm compositions between groups of farmers and under contrasted environmental conditions. We listed these attempts and compared their outcomes, to review the potential for the ShadeTreeAdvice methodology to investigate sources and drivers of farmers' LEK through a quantitative approach. Furthermore, we detail the methods used by authors to select their respondents and discuss the impacts of their sampling methods.

2.6 | Improvements in ShadeTreeAdvice

Since the inception of the ShadeTreeAdvice methodology in 2016 (van der Wolf et al., 2016) researchers and practitioners have identified its strenghts and been confronted with its limitations. They tested improvements through trials and errors, notably to help investigating sources and drivers of LEK, to test robust methods of validation of the results, or to further convert the results into practical recommendations to farmers. Based on their feedback, we review the limitations and suggest a series of improvements in the ShadeTreeAdvice methodology to better guide practitioners in future studies. Furthermore, we discuss feedback received from users of the decision-support tool and suggest avenues to improve it and contribute to its better integration in the design of agroforestry programs.

3 | RESULTS AND DISCUSSION

Studies following the ShadeTreeAdvice methodology are by definition grounded in a local context, reflecting the fact that farming systems, shade tree species and LEK are all context specific. In particular, LEK is specific to a set of environmental conditions, local practices and perceptions, and should not be taken out of its context (Charnley et al., 2007; Tebboth et al., 2020; Tusznio et al., 2020). Keeping in mind the challenges inherent to a review of studies grounded in local contexts and the limits of LEK comparison, we highlight in this section general findings in line with the common comprehension of tropical agroforestry systems and with studies pertaining to LEK and tree species, thus demonstrating the relevancy and reliability of the ShadeTreeAdvice approach.

3.1 | Shade tree species and their perceived performances

Ecological conditions, partial use of indigenous tree species, socio-economic factors, and access to market all lead to a huge variety in tree species used between different study sites (a total of 135 different species in the six studies on *Coffea arabica*). This makes comparisons on species level challenging, as only eight tree species are present in more than two study sites. One approach consists in comparing at family levels instead. When comparing the five highest ranked tree species for soil regulatory services between the studies, *Fabaceae* and *Moraceae* were identified as the most common families found in five different countries (Figure 1). *Fabaceae* is a large, diverse and widely distributed family. It is not only the most common family for the highest ranked tree species for soil regulatory services but, with 23 different species (17% of all species), it is also the most common family in the rankings of all studies. *Albizia schimperiana* and *Leucaena leucocephala*, the highest ranked tree species for soil regulatory services in Tanzania and Vietnam belong to this family. The prevalence of tree species from

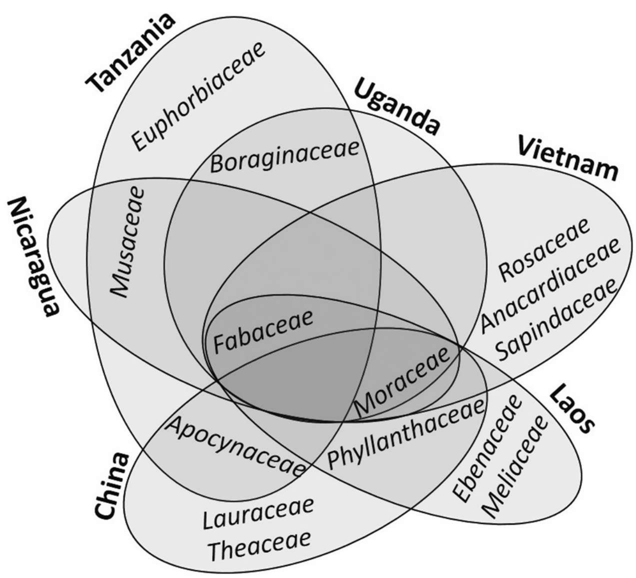


FIGURE 1 Shade tree families ranked in the top five for soil regulation services in the different rankings

the *Fabaceae* family is a feature frequently observed in smallholder coffee farming systems (Hundera, 2016; Tscharntke et al., 2011), explained by their ability to form atmospheric nitrogen-fixing symbiotic relationships with rhizobia bacteria and contribute to soil fertility. Their leaves, usually being compound, also provide light shade conditions suitable for coffee. Two other tree species were noticeable. *Bischofia javanica*, which belongs to the diverse family *Phyllanthaceae*, was the highest ranked tree species in China and Laos for improving soil fertility. The crown of *B. javanica* is denser but was perceived as beneficial to soil fertility due to high amounts of leaf litter and increased nutrient cycling (Rigal et al., 2019). *Cordia africana* (family *Boraginaceae*) was the highest ranked tree species for improving soil fertility in Uganda and is known for providing good mulch.

Rankings of tree species were quite similar within study sites for services related to soil regulation as discussed above, coffee production (yield, quality, and life expectancy of coffee trees), and the tree attribute "providing good quality shade". If a tree species was ranked in the top five for one of these services or tree attributes, it was very often also ranked high for the two others. In Tanzania and Uganda, this was the case for four of the five tree species, and in Laos, Vietnam and Nicaragua, for two. The highest ranked species was also the same for all selected ES in Tanzania (*A. schimperiana*), Uganda (*C. africana*), and Vietnam (*L. leucocephala*). These tree species were also frequently highly ranked for other ES not directly linked with coffee production. This raised the question of whether these tree species are exceptional in providing several beneficial services or if their high ranking is due to biases in farmers' perceptions. The ShadeTreeAdvice methodology could not always help clarify this point. Further comparison with existing academic knowledge when possible, or comparison of perceptions between groups of farmers potentially less prone to biases, could help clarify this point in future studies.

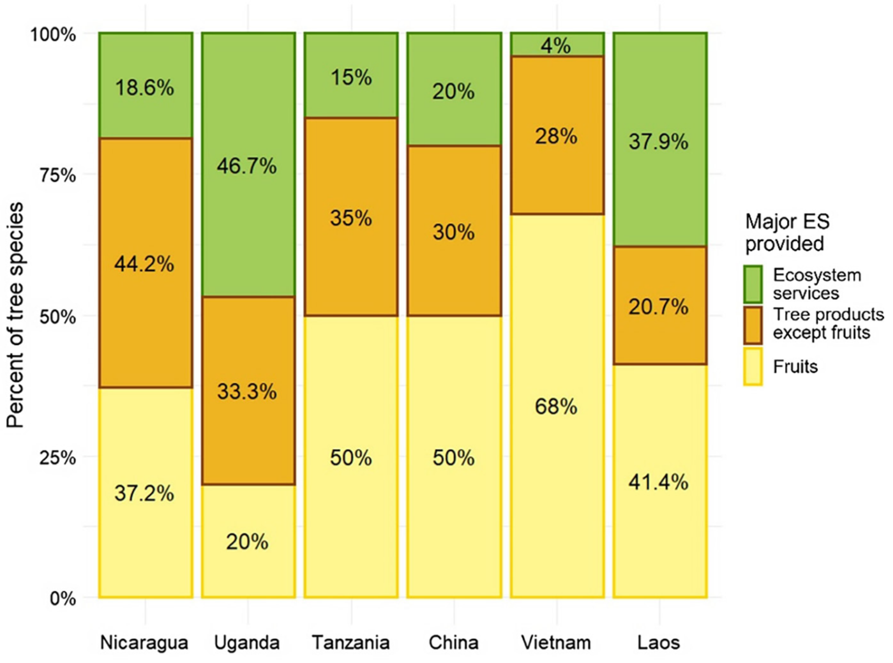
Fruit trees were frequently ranked in the studies, not surprisingly considering that farmers ranked fruit provision as an important ES in four out of six ShadeTreeAdvice studies (Table 2). When categorized under the most important benefit they provide (trees for fruits, trees for other products or trees for ecosystem services), between 20% and 68% of the ranked species in every study sites belonged to the fruit tree category, with 44 different species overall (and 33% of all species) (Figure 2). The four shade tree species most common across studies were all fruit trees, confirming their importance and showing that they are more widely spread across the world compared to other tree species. *Psidium guajava* and *Mangifera indica* were ranked in all six studies. *Persea americana* and *Artocarpus heterophyllus* were also widespread and ranked in five studies, with *Persea americana* only absent in China and *A. heterophyllus* only absent in Nicaragua. Several *Citrus* spp. were included in the rankings making this genus the most common, even though none was ranked in Uganda or China. This genus was followed by *Musa*, *Psidium*, *Persea*, *Ficus* and *Mangifera*, all ranked on all three continents.

Some differences between countries can be observed. Vietnam had a much higher proportion of fruit trees than other countries (68%). High levels of chemical inputs and overall good access to market

TABLE 2 Number of times the ecosystem services, shade tree attributes, and farming practices were used for ranking tree species in the studies on Arabica coffee. (*) indicates reports of knowledge gaps and difficulties of analysis by authors. (!) indicates that authors excluded an ES from analysis due to knowledge gaps. The last column presents the mean percentage across the six studies (± standard error) of pairs of tree species with significantly different scores

Rankings		China	Laos	Nicaragua	Tanzania	Uganda	Vietnam	Total	Pairwise comparison
Ecosystem services	Soil regulation	4	2	2 (!)	3	3	4 (*)	18	73% ±8%
	Microclimate regulation	2	3	(!)	2	1	3	11	79% ±9%
	Coffee production	1 (!)	2		2	2	1 (*)	8	77% ±11%
	Tree products (timber, fuelwood, fodder)			2	2	2		6	76% ±12%
	Tree products (fruits)	1		2	1	1		5	76% ±4%
	Weed control	1	1		1	1		4	80% ±12%
	Pest and disease control	(!)		(!)		2 (*)		2	59% ±2%
	Biodiversity		1				1	2	87% ±7%
Shade tree attribute	Shade provision		1	1	1		1	4	77% ±8%
	Growth rate			1				1	—
	Adapted to local conditions			1				1	—
Farming practice	Shade tree pruning			1				1	—
	Fertilizer input						1	1	—

FIGURE 2 Proportion of trees providing fruits, trees providing products other than fruits (timber, fuelwood, and fodder), and trees providing other ecosystem services (soil fertility improvement, provision of shade cover, etc.) in the studied countries



explain why farmers in Vietnam prioritize the production of fruits over ecosystem services. Another contributing factor is favourable government policies. With economic benefits being the most important driver for the majority of farmers in this region, some farmers plan to replace coffee with fruit trees when fruits are more profitable than coffee. Other tree products (timber, firewood, and fodder) were not a priority in China, Vietnam and Laos (Table 2). The proportion of these tree species was below 30% in these countries, while it was above 30% for Nicaragua, Uganda and Tanzania. This shows the influence of farmers' priorities and socio-economic conditions on the selection of tree species. The history of farming systems is another important factor. One scenario is the transition from monocrop to agroforestry system with farmers actively deciding which tree species to plant. This selection can also be influenced by promotions, for example the "Lao Upland Development Project" promoted local legume trees for shade (Lépine, 2018), which might contribute to the high proportion of trees solely for ecosystem services. Another setting is the transition from formerly forested land. Here, farmers decide on which trees to remove. In this scenario, it could happen that more tree species providing ecosystem services remain on the farm, which might have been the case for Uganda. This setting is also common in farming systems where trees can regenerate naturally. The choice becomes then more opportunistic in nature, compared to farming systems where purposeful planting of seedlings is the norm. For the latter, the choice of trees is more directly linked with the benefits and ecosystem services sought by the farmer. This was especially the case in Uganda.

3.2 | Ecosystem services and knowledge gaps

The number rankings for tree products, whether food, timber and other non-timber tree products, highlights the importance of provisioning services (Table 2). It emphasizes the importance of economic benefits in farmers' priorities, sometimes over environmental benefits (Chechina & Hamann, 2015; German et al., 2006), and calls for widening the methodology beyond sole environmental services to better capture and reflect farmers' needs (Nath et al., 2016; Tusznio et al., 2020). More generally, the diversity of rankings considered locally important by farmers corroborates a holistic vision of their farming systems and supports their preferences for multipurpose tree species (Mekoya et al., 2008).

Ecosystem services related to soil regulation were the most common in the six LEK studies on Arabica coffee, with a total of 18 rankings (Table 2). Yet, only one study specifically mentioned competition from root systems. Most indicators related to litter and soil erosion, therefore visible indicators, hinting at a knowledge gap on belowground impacts and root distribution (Reubens et al., 2011). ES related to coffee production, which encompassed coffee yield, coffee quality and life expectancy of coffee trees, were only ranked a total of 8 times despite their major importance for coffee farmers. This low number of rankings can partly be explained by difficulties to rank the impacts of shade trees on coffee quality (Rigal et al., 2018) and could indicate a knowledge gap in coffee producing regions, where farmers either do not drink coffee or are not economically incentivized to produce high quality coffee. The impact of shade trees on pests and diseases is of particular importance as it was reported as a major concern in all study areas. However, rankings could not be conducted in China and Nicaragua, due to knowledge gaps. Only two rankings were reported in Uganda, and they highlighted the difficulty of conducting rankings for these regulatory services due to challenges in the analysis.

Pairwise comparisons of tree species' scores using Wald tests provided another pathway to confirm the above knowledge gaps. The lower this percentage, the more inconsistencies in farmers' rankings

TABLE 3 characterization of respondents in the 8 studies conducted between 2016 and 2020

Country	Source of farmers' contact	Social factors	Farm size and dependency on coffee/cocoa	Market integration	Land tenure	Reference
Ghana	Cooperative, certification, other	–	–	–	–	Graefe et al. (2017)
Uganda (a)	–	Gender	Smallholder farmers (<2 ha)	–	–	Gram et al. (2017)
Laos	Cooperative	Gender	Smallholder farmers, 72% of income from coffee	Direct links to specialty market	Long term lease from government	Lépine (2018)
China	Certification, extension workers	Gender, ethnic minority	Smallholder farmers (<2 ha), workers from large coffee farms, farm managers	Direct links with national and international agribusinesses	Long term lease from government	Rigal et al. (2018)
Uganda (b)	–	–	–	–	–	Bukomeko et al. (2019)
Tanzania	NGO, other	Gender, involvement with NGO	Smallholder farmers (<1 ha)	–	–	Wagner et al. (2019)
Nicaragua	NGO	Gender, age	Farmers (<5 ha), with >65% of land dedicated to coffee	Poorly connected to roads and markets	Tumultuous history of land distribution and appropriation	Carpente (2020)
Vietnam	Extension workers	Gender, ethnic minorities	Smallholder farmers (<2 ha), with 65% dedicated to coffee	Medium/well connected to roads and markets	–	Nguyen et al. (2020)

and perceptions of tree species impacts. Even within the ecosystem services related to soil regulation, differences can be observed. An overall similar perception among farmers and high agreement on the higher performances of some shade tree species over others was indicated for mulch provision (an average of 77% ± 9% of all pairwise comparisons of tree species scores were significantly distinct [four rankings]). This was also indicated for erosion control (average of 69% ± 5% [four rankings]), while there was less agreement among farmers for root competition (only 62% [one ranking]), confirming that visible ES were easier to rank, while belowground ES were more often associated to knowledge gaps. The same analysis conducted on regulation of pests and diseases provides another example of the way pairwise comparison can support the identification or confirmation of knowledge gaps. The rankings related to pest and disease regulation brought the least information on shade tree species impact, with an average of only 59% ± 2% of all pairwise comparisons being significantly distinct (two rankings). Therefore, this result supports the fact that there is a knowledge gap on the impact of shade tree species on pests and diseases regulation, and that further research in these complex biotic networks is needed to fill these gaps and complement LEK (Liebig et al., 2016; Mistry & Berardi, 2016).

3.3 | Linking LEK to socio-economic groups and environmental factors

In order to ensure the reliability of LEK and of subsequent recommendations from the online tool, priority should be given to gathering knowledge from local experts rather than from a pool of respondents representative of the study area (Davis & Wagner, 2003; Ruddle & Davis, 2013). These local experts should be agroforesters with first-hand experience of ES provision by shade trees. The richer the respondents' experience, the more comprehensive the results (Cerdán et al., 2012). Most ShadeTreeAdvice studies relied on existing databases of cooperatives, NGO programs, and certification schemes to identify smallholder farmers with agroforestry systems, considered local experts (Table 3). Extension workers provided an alternative source of contact information to identify local experts. One consequence is that interviewed farmers are often better linked to market and international projects than average farmers in the study area. This could have an influence on the LEK as well since these farmers could be influenced by tree species promotion or the knowledge of the extension service. Most studies then used random sampling techniques to extract a sample of farmers from within these databases of local experts, or used semi-random techniques to include representatives of major socio-economic and demographic groups in their sample, often with a specific focus on gender (Table 3). Characterizing cultural, socio-economic, and demographic groups is important since LEK is known to be associated with criteria such as gender (Ayantunde et al., 2008), age or migration (Mathez-Stiefel et al., 2012), and ethnicity (Yuan et al., 2014). It can also be associated with farming practices, as shown by Cerdán et al. (2012) who pointed out a deeper understanding of trees' impacts from organic farmers than conventional farmers. Not only LEK but also preferences and priorities are related to respondents, as Tebboth et al. (2020) pointed out with their study on invasive species and the fact that ES can simultaneously be considered beneficial by some stakeholders and detrimental by others. Farmers with land tenure issues and low access to market will also exhibit different priorities than farmers in less vulnerable states (Nath et al., 2016). Characterizing these factors and understanding the differences in perceptions and priorities associated with them helps to tailor recommendations to answer farmers' specific needs. To carry out this analysis under the ShadeTreeAdvice methodology, researchers can run separate Bradley-Terry or Plackett-Luce analyses on subgroups and compare the resulting tree species' scores, or directly add co-variables into the mathematical model (Turner et al., 2020; Turner & Firth, 2012). This depth of analysis corroborates the use of the ShadeTreeAdvice methodology to document LEK, and can help researchers validate their results and recommendations.

Following this method, ShadeTreeadvice studies highlighted the many differences in perceptions and priorities between socio-economic groups. For instance, ethnicity was related to differences in perceptions and preferences in China (Rigal et al., 2018): farmers from mountainous ethnicities were more eager to select indigenous tree species than farmers from lowland ethnicities, even though they perceived higher belowground competition from these tree species than farmers from lowland ethnicities did. In Tanzania, women perceived *Musa spp* as more beneficial for soil fertility while men preferred *Rauvalfia caffra* for the same ES (Wagner et al., 2019) while, in Nicaragua, women had more difficulties than men to rank tree species for soil fertility (Carpente, 2020). In Vietnam, proximity to roads was the most important factor influencing the overall preference of shade tree species: farmers in close proximity to roads and hence market access mostly selected fruit tree species, while farmers in more remote areas preferred timber and N-fixing tree species (Nguyen et al., 2020). On the other hand, ShadeTreeAdvice studies rarely discussed land tenure status and farmers' linkage to market and extension services (Table 3). Researchers using ShadeTreeAdvice should carefully document these aspects in future studies, and better characterize the social, economic, and cultural context prior to selecting their pool of local experts. The pool of local experts does not need to be perfectly representative of the community. Gathering reliable and accurate LEK is the first priority of the methodology. Yet, the gathered LEK must result in tailored recommendations for wealthier farmers as well as more vulnerable or marginalized farmers.

Differences in priorities and perceptions were also related to agroecological conditions. For instance on Mount Elgon in Uganda, farmers at high elevation gave higher priority to mulch provision and erosion control while farmers at low elevation gave higher priority to microclimate regulation (Gram et al., 2017). In Laos, differences in species preferences were associated with soil fertility, with the N-fixing *Erythrina ovalifolia* better ranked in more fertile areas (Lépine, 2018).

This quantitative methodology proved suitable to study differences in perceptions among groups of farmers. Yet, its accuracy diminishes when running analyses on subgroups with few individuals and rankings. This could explain the difficulty to detect differences between men's and women's perceptions and preferences (Lunelli et al., 2016; Sari et al., 2020), especially considering the difficulty of having gender-balanced pools of interviewees. Only two studies relying on the ShadeTreeAdvice methodology detected differences (Carpente, 2020; Rigal et al., 2018). In future studies, the addition of a last ranking dedicated to overall preferences (section 3.4.3) should help highlight differences in gender priorities (Meemken et al., 2017). New mathematical models to identify clusters of respondents based on their rankings could also prove fruitful in this regard (Biernacki & Jacques, 2013).

Lastly, while analysing the differences in priorities and perceptions, attention must be paid to potential collective biases from respondents. Quantitative approaches allow the comparison of LEK between different groups of farmers and can help identify biases and knowledge gaps during the validation process (Rigal et al., 2018). However, this approach is limited and must be complemented with qualitative statements from farmers to identify the sources of their LEK in an attempt to identify potential biases. This was particularly evidenced in China and Laos, where it was shown that promotion campaigns of shade tree species had a strong impact on farmers' preferences and perceptions. In China, farmers had a positive bias for the nine shade tree species promoted by local governments despite their competitiveness with coffee (Rigal et al., 2018). In Laos, farmers ranked *E. ovalifolia* much higher than any other shade tree species for all ES, partly as a result of past programs promoting that species and of its current widespread use (Lépine, 2018). This difficulty to identify collective biases calls for improved methodological steps to validate the results.

3.4 | Improvements

The ShadeTreeAdvice methodology successfully allowed the collection and analysis of farmers' perceptions of over 160 tree species and eight categories of ES in the eight study areas (Table 1). These studies therefore demonstrated the relevance and efficiency of this methodology in documenting LEK to recommend shade tree species. Yet, this review also shows the need to further improve the methodology. The methodology would particularly benefit from clear steps to gather more comprehensive LEK and validate the results. According to researchers and extension services, it would also be beneficial to convert tree species' scores into sharper recommendations for farmers on the ShadeTreeAdvice online tool. Here, we suggest a series of four methodological modifications directly applicable in future studies and discuss the need for future improvements to the online tool.

3.4.1 | Comparing the tree performances against performances in the absence of shade trees

The scores resulting from the ShadeTreeAdvice methodology allow the comparison of tree species' performances, to assess which species provide the most of a targeted ES and which provide the least. In the context of an agroforestry system, the ShadeTreeAdvice tool can therefore help identify the best-suited shade tree species. However, it does not offer a comparison point with a monoculture system without shade trees. In the context of conversion from monoculture to agroforestry, it cannot help assessing whether or not this conversion will be beneficial for a set of targeted ES. In other words, the scores do not inform farmers whether coffee or cocoa agroforestry systems will perform better or worse than in the absence of shade trees, equivalent to a monoculture scenario.

This point can be illustrated by shade tree species' impact on coffee production on Mount Elgon, Uganda. Based on recent ecophysiological models (Rahn et al., 2018), shade is known to be beneficial for yield at low elevations in this mountainous region. We can therefore infer that coffee yield would be higher under *C. africana*, the tree species with the highest scores for coffee yield, than in monoculture systems. But would it still be higher under *Terminalia ivorensis* or *P. americana* (two species with low to medium scores for coffee yield) than in monoculture systems? Current information from ShadeTreeAdvice studies does not give users information in this regard.

A simple change in step 3 of the ShadeTreeAdvice methodology can yield this information in future studies. In past studies, interviewees selected and ranked up to 10 cards representing tree species with which they were familiar. In future studies, we suggest that interviewees select an additional card representing the absence of shade trees. Ranking exercises can proceed with this new set of cards. In this new configuration, the Bradley-Terry (Turner & Firth, 2012) or Plackett-Luce (Turner et al., 2020) analysis will attribute scores and standard deviations to the absence of shade tree, reflecting the performances of a monoculture scenario for the chosen set of ES. In this new configuration, monoculture (equivalent to the absence of shade trees) can serve as a reference: tree species ranking higher than monoculture systems provide services, whereas tree species ranking lower than monoculture systems provide disservices (Figure 3). This change would benefit not only the end users with more precise information; it would also add a reference point to ease the comparison between tree species' scores and scientific studies on shade tree provision of ES. Therefore easing the validation of the results.

3.4.2 | Going beyond ecosystem services with farming practices

One of the underlying assumptions behind the rankings of shade tree species for locally important ES is that ES are the main drivers for shade tree species selection. Yet, they are not the sole drivers of shade tree species selection. Bukomeko et al. (2019), highlighted the fact that the ES selected in their study did not always match farmers' needs. Wagner et al. (2019) also emphasized the importance of taking into account the history of farming systems as well as more decision-making criteria to understand farmer choices and on-farm tree diversity. In both studies, the set of prioritized ES only partly explained on-farm tree diversity. We therefore suggest widening the rankings to any objective deemed relevant by local farmers, and in particular to the impact of shade trees on farming practices. For instance, intercropping coffee with fruit trees requires additional management of fertilizer and pesticide inputs, pruning, and harvesting, which raises the issue of labor availability during harvest seasons. Fast growing tree species like *L. leucocephala* decrease the labor needed for field weeding, but require regular pruning and thinning to control shade and the many offsprings. These management factors influence farmers' selection of fruit trees or other tree species they intercrop with coffee, and should therefore be included in the tree selection tool alongside the tree species provision of ES.

Two studies on the need for fertilizers in Vietnam and ease of pruning in Nicaragua have already started investigating the impact of shade tree species on farming practices. These studies show that the ShadeTreeAdvice methodology is well suited to score shade tree species not only for their provision of locally important ES but also for their impact on farming practices. Only step 2 of the methodology needs to be adapted to accommodate this change. While identifying locally important ES, researchers should also identify the locally important farming practices impacted by shade trees. Importantly, researchers should pay attention that the identification of locally relevant ES and farming practices covering the priorities of all farmers in the study area, including vulnerable and marginalized ones. The rest of the methodology remains unchanged. We therefore advocate for future studies to better balance tree rankings on the provision of ES and their impacts on farming practices, in order to better reflect the needs of farmers and their main decision-making criteria. This is especially important in intensive farming regions such as in Southeast Asia, where short-term economic benefits and labor availability are key constraints, and often influence tree species selection more than their impact on soil fertility or microclimate regulation.

3.4.3 | Validation of results

After the collection and analysis of LEK, a thorough validation process of the results must ensure accurate recommendations to farmers (Ruddle & Davis, 2013). Researchers shall keep in mind that LEK represents an autonomous body of knowledge and that the validation process should not be seen as a mere validation of LEK by scientific standards (Mistry & Berardi, 2016; Uprety et al., 2012). Still, marked dissimilarities between LEK and academic or expert knowledge should raise a flag passed on to end-users to present the various points of view, in order to give them all the elements guiding their decision-making process. These flags could equally reflect differences in tree performances between studies due to differences in local conditions (Liebig et al., 2016), differences in perceptions due to differences in priorities among stakeholders (Tebboth et al., 2020), collective bias in perceptions (Valencia et al., 2015)

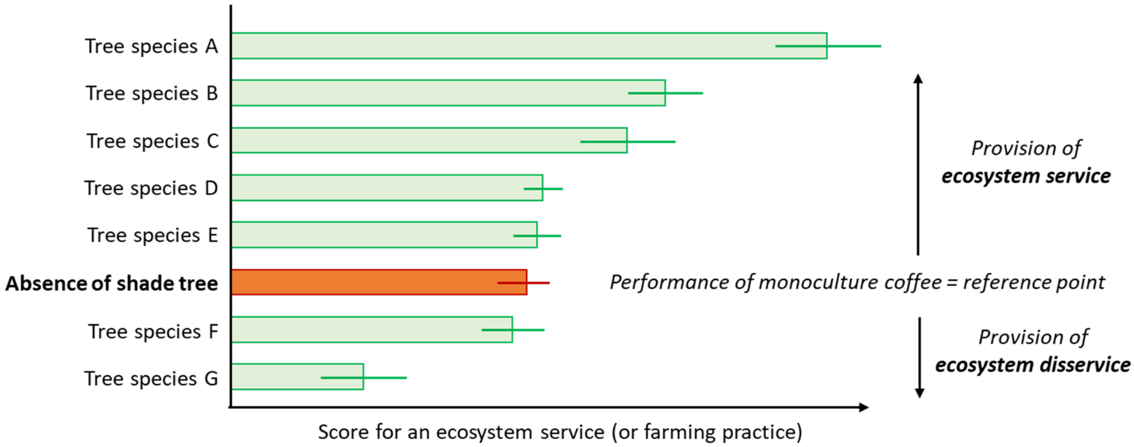


FIGURE 3 Illustration of scores after the addition of a card representing the absence of shade tree during rankings. The scores include coffee monoculture as a reference point to determine whether shade tree species have a positive or negative impact on the selected ecosystem service

as they could reflect scientific mistakes (Fremout et al., 2021) or knowledge gaps and the need for further research on a specific topic (Mistry & Berardi, 2016).

The ShadeTreeAdvice methodology already provides numerous avenues for validation of the results. The first lies in the quantification of tree performances through scores associated with standard errors (Turner & Firth, 2012). The standard errors are indicators of uncertainties, either highlighting knowledge shared among only few respondents or discrepancies in perceptions among the respondents. The comparison of LEK between different groups of respondents is a second avenue for validation as it can help point out disagreements and biases in perceptions (Cerdán et al., 2012; Rigal et al., 2018). Previous ShadeTreeAdvice studies have also often conducted focus group discussions at the end of the study, to present, discuss and validate the results with communities in the study area. Yet, the ShadeTreeAdvice methodology lacks clear guidelines to do so.

We suggest two new methods to guide the validation of results, based on trials and errors from previous studies. The first method consists in checking whether the results from the ShadeTreeAdvice methodology can link farmers' priorities with their current farming systems. To do so, researchers check if tree species present on the farm, and identified through on-farm inventory, display high scores for the ES considered priorities by the farmer. The second method consists in checking whether the recommendations from the ShadeTreeAdvice tools are relevant in the case of a conversion from monoculture to agroforestry. To do so, researchers include an additional ranking exercise in step 4, equivalent to farmers' overall tree species preference if given a new monoculture plot. Researchers then check if the preferred tree species match the tree species identified by the ShadeTreeAdvice tool given the respondents' set of priorities for this new plot.

Marked differences between ShadeTreeAdvice outputs and farmers' current practice or overall preferences would highlight disagreements in shade tree species' scores and perceived performances, or most likely indicate the omission of important decision-making criteria for selecting and keeping shade tree species. The identification of important yet omitted decision-making criteria would require researchers to go back to step 2, and raise the importance of going beyond sole rankings for ES as drivers of tree species selection.

3.4.4 | Investigating functional traits

The ShadeTreeAdvice methodology enables documenting a wide range of tree species, including species known by farmers but not documented from field trial experiments. However, the methodology does not enable documenting the least common tree species, those for which farmers have little to no experience. Another limitation lies in that it is hard to compare farmers' perceptions between study sites, as only a few tree species are common between study sites, the majority being fruit tree species. Even the scores of the common fruit tree species cannot be easily compared between study sites, as scores are only meaningful when compared to other species ranked in the same study area, under similar growing conditions, and in similar farming systems. This results for example in *M. indica* being ranked within the top five tree species for improving coffee production, soil fertility, and shade cover in Vietnam, while it was ranked lower in other countries. Lastly, the scores indicate tree species performances but they do not explain why some tree species perform better than others.

One solution to complement the methodology and accommodate the above limitations could be to look at functional traits of the different tree species. If correlations between functional traits and provision of certain ES are drawn, functional traits could be used as a proxy for explaining and extending the findings of future ShadeTreeAdvice studies toward the least common shade tree species (Funk et al., 2017; Lamond et al., 2016; Smith Dumont et al., 2018). They could also be used as reference points to allow for better comparisons between study sites. For instance, it appears that *A. schimperiana*, *L. leucocephala*, and *E. ovalifolia*, all belonging to the *Fabaceae* Family, dominated the rankings across the studies for improving coffee production (yield and quality), providing shade, and improving soil fertility (improving soil moisture and providing good quality mulch). The functional traits of this family, especially the capacity to fix nitrogen and provide homogenous shade cover through composite leaves, seem to be very beneficial for inclusion in coffee agroforestry systems. It hints that other tree species from the *Fabaceae* family, with similar functional traits, could have similar impacts. Furthermore, the highest ranked tree species in China for coffee production (*Phyllanthus emblica*) has very small leaves and hence might provide a similar shade cover as many species of the *Fabaceae* family. Lastly, comparing the relationships between functional traits and provision of ES derived from LEK with those displayed in academic studies would provide a last avenue for validation of the results (Hastings et al., 2020; Hundera, 2016). Through a finer understanding of farmers' LEK, these relationships could also help explain discrepancies in perceptions if these arise from the new validation process suggested in step 6. In future studies, we advise investigating the tree functional traits and their relationship with ES and farming practices through focus group discussions, expert interviews, or by conducting a literature review during the validation step.

In its current version, the ShadeTreeAdvice methodology already leads to the collection of qualitative knowledge during interviews, when farmers are asked to comment on their rankings. It not only allows the interviewers to ensure that interviewees have understood the ranking exercise, but also reveals some of the links between tree performances and tree attributes, and refines the understanding of farmers' drivers for tree selection and management practices (Lamond et al., 2016). The methodology therefore already results in the collection functional traits and tree attributes, however it does not currently provide room for the management of this ecological knowledge and these comments are neither used in the statistical analysis nor documented and displayed in the current version of the ShadeTreeAdvice website. Given appropriate time, researchers could combine the ShadeTreeAdvice methodology with the AKT methodology to combine quantitative with qualitative analysis. Indeed, Smith Dumont et al. (2018) effectively combined both approaches in Rwanda, using the AKT tool to map the interactions between tree attributes and coffee yield, and analysing rankings of tree attributes to identify shade tree species compatible with high coffee productivity.

All of the above improvements to the ShadeTreeAdvice methodology are summarized in Figure 4.

3.5 | Practical recommendations from LEK and the decision-support tool

Most studies on LEK point out the depth of knowledge of practitioners and call for better integration of their LEK into policies and restoration programs (de Albuquerque et al., 2009). Yet, only a few studies go all the way to practical recommendations and decision-support tools (Fremout et al., 2021; Reubens et al., 2011; Uprety et al., 2012). Since the inception of the ShadeTreeAdvice methodology, results of the studies have been uploaded online to feed such a decision-support tool and help farmers select shade tree species. A thorough validation process of the results is a prerequisite to uploading the results online (Ruddle & Davis, 2013). The tool then allows users to select a set of ES representing farmers' needs. It combines the scores of shade tree species for this set of ES and displays the results in a chart. Users can use this chart as a starting point, screening through the list of tree species to select a combination of species that provide a good balance in terms of performances for the set of select ES. Results from the eight initial studies show that best performing tree species depend on the set of selected ES, therefore confirming that shade tree selection needs to be tailored to match farmers' needs (Bukomeko et al., 2019; Meemken et al., 2017). Tree species providing good trade-offs among ES often rank higher than species maximizing one ES at the expense of other services, therefore corroborating the fact that multipurpose tree species are favoured (Cerdán et al., 2012; Mekoya et al., 2008). Lastly, it also confirms that several tree species often provide similar trade-offs, thus showing that there is no single best tree species, and that recommendations should emphasize combinations of tree species (Tscharntke et al., 2011).

In its current form, the tool is not tailored to be directly used by end-beneficiaries of the solutions (farmers). It is better suited to trained extension agents who can subsequently make recommendations to farmers, based on their livelihood needs. Eventually, recommendations from the tool could also be used in the setup of shade tree nurseries or in the development of a landscape strategy that goes beyond the individual farmers to tackle challenges such as soil conservation in a hot spot prone to erosion, or connectivity between patches of protected areas (Lake et al., 2018; Vaast et al., 2005). In fact, there are many potential users for such a tool. As a web-based tool, the assumption that smallholder farmers will be the major users might ultimately be wrong since the majority of smallholder farmers do not have internet access. Furthermore, the information from the tool is currently only accessible in English. Early users based in China already identified that language and the lack of local names could be major barriers to using the tool. User research to identify the needs, difficulties, and barriers of the target users, and package information into something useful is fundamental in order to design a tool that will ultimately be beneficial for farmers. It can be based on methods such as human-centered design and participatory experiments with short learning loops (Kenny et al., 2021).

Current feedback from users already hint at the need for recommendations on management practices, and more specifically in planting density and suitable level of shade. While there is no straightforward answer, as suitable levels of shade are context specific (Rahn et al., 2018), there is potential to add recommendations on farming practices and spatial arrangements based on LEK, such as spacing between trees, tree thinning as they mature, or species more

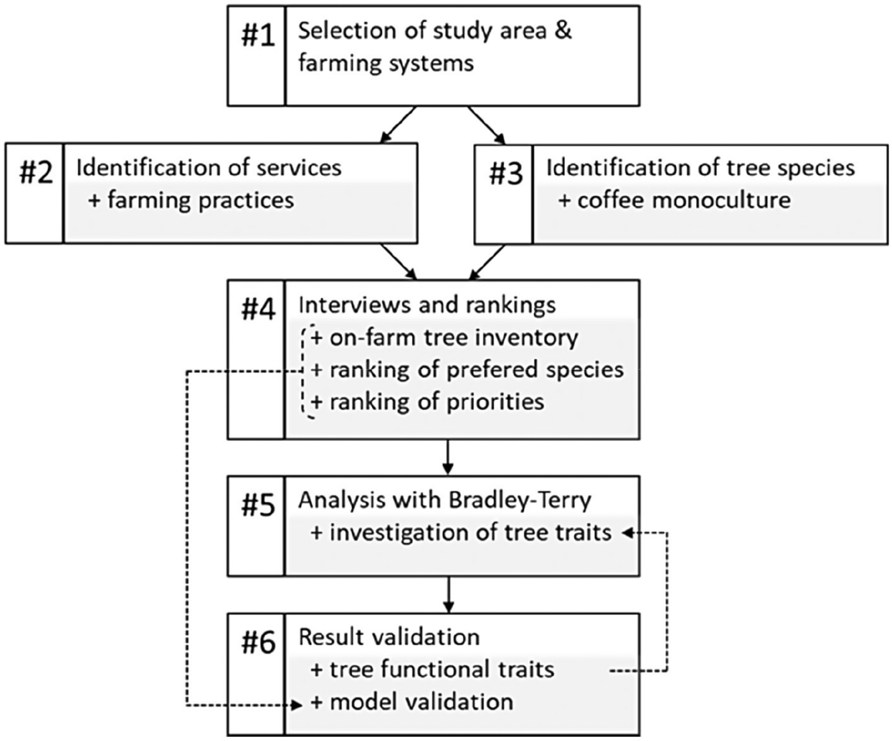


FIGURE 4 Flow chart of the improved ShadeTreeAdvice methodology. Steps defined by van der Wolf et al. (2016) are underlined in white, edits and suggested improvements are underlined in grey

suitable as hedgerows (Charnley et al., 2007; Mariel et al., 2021). In future versions of the ShadeTreeAdvice tool, recommendations for combinations of shade tree species should also be completed with recommendations for relevant temporal designs. The temporal design should maximize the benefits along the system lifespan, hence not only in the long run but also during the initial stages of the conversion toward agroforestry. For example, short-cycle annual crops or fast-growing oil palms planted alongside cocoa trees can rapidly control competitive weeds, while other native shade tree species are established to build up a suitable tree canopy in the longer run (Jagoret et al., 2012). Considering that access to germplasm is another common limitation to planting tree species (Smith Dumont et al., 2019), information on seed collection and propagation could also be added (Fremout et al., 2022). More generally, the tool could be linked to existing tree libraries, such as the ICRAF tree library (http://db.worldagroforestry.org/), to retrieve additional information about tree species. Lastly, the map of ShadeTreeAdvice studies could indicate ecological zones to help users select the environmental factors closest to their conditions whenever this choice is given.

Finally, the current version of the tool provides a snapshot of farmers' needs and farmers' perceptions of shade tree species performances at the time of the study. Considering that LEK is known to be dynamic and that farmers' perceptions are likely to evolve with time (Charnley et al., 2007), for instance through changes in their farming systems and local contexts or with the introduction of new candidate species in the area (de Albuquerque, 2006), there is a need to make the tool more dynamic. This is corroborated by the fact that farmers' needs and constraints are also likely to evolve with time, and that new challenges are likely to appear, especially with climate change or the spread of new pests and diseases (Bukomeko et al., 2018). For these reasons, future versions of the ShadeTreeAdvice tool should encompass a digital space where practitioners using the tool can enter feedback. Feedback would be accessible to subsequent users and supplement the results, based on initial perceptions of tree performances at the time of the study, with additional information useful to put them into perspective.

4 | CONCLUSION

The initial eight ShadeTreeAdvice studies validate the original objectives of the methodology and associated tool. The methodology succeeds in providing an efficient way to gather and analyse farmers' local ecological knowledge, and to feed the results into a decision-support tool to make tailored recommendations of tree species that cater to needs and constraints in agroforestry systems. This method quickly provides reliable foundations for a diversity of tree species and their impacts on a wide range of ES. Further studies, and in particular agronomic and botanical experiments, can afterward complement the results and focus on filling in specific issues raised by knowledge gaps. The eight studies also validate the suitability of the method in a diversity of farming systems based on perennial crops (Arabica coffee, Robusta coffee and cocoa insofar), and in a variety of locations, social, cultural and agroecological contexts across continents.

Based on these experiences, we advise simple changes and adjustments to further improve the methodology, without increasing its overall complexity nor significantly increasing the time necessary to conduct the study: (i) adding one element to represent coffee monoculture as a reference in the rankings; (ii) extending the scope of tree impacts beyond that of ecosystem services to farming practices; (iii) using tree functional traits as an avenue to generalize results; (iv) adding a ranking step to reflect overall tree species preferences and farmers' priorities to validate the results. Lastly, we recommend researchers to better document the social, economic, and cultural aspects of the study areas prior to selecting respondents, and keep a critical eye on the links between LEK and the socio-economic and cultural characterization of respondents. New studies are already underway testing these improvements, while further extending the ShadeTreeAdvice database (www.shadetreeadvice.org).

Future avenues for improvement should focus on the decision-support tool itself, to better reflect the dynamic nature of both agroforestry systems and local ecological knowledge. In addition, its design should be more user-oriented, keeping in mind that primary users are not necessarily farmers but more likely public and private extension services, NGOs an,d tree nursery managers. With these improvements, ShadeTreeAdvice can eventually develop into an even more efficient method for the promotion of tailored agroforestry systems across locations and perennial cropping systems.

AUTHORS' CONTRIBUTIONS

All authors contributed to developing the main ideas and framework of the paper. C.R. and S.W. carried out the database analyses; C.R., S.W., M.P.N. and L.J. contributed to the writing process. All authors took part in editing the manuscript.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

All data used in the present article was retrieved from the ShadeTreeAdvice studies referenced in Table 1. The tree database is publicly available on www.shadetreeadvice.org.

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REFERENCES

Abdulai, I., Vaast, P., Hoffmann, M. P., Asare, R., Jassogne, L., Van Asten, P., Rötter, R. P., & Graefe, S. (2018). Cocoa agroforestry is less resilient to sub-optimal and extreme climate than cocoa in full sun. *Global Change Biology*, *24*, 273–286. https://doi.org/10.1111/gcb.13885

Ayantunde, A. A., Briejer, M., Hiernaux, P., Udo, H. M. J., & Tabo, R. (2008). Botanical Knowledge and its Differentiation by Age, Gender and Ethnicity in Southwestern Niger. *Human Ecology*, *36*, 881–889. https://doi.org/10.1007/s10745-008-9200-7

Barber, M., & Jackson, S. (2015). 'Knowledge Making': Issues in Modelling Local and Indigenous Ecological Knowledge. *Human Ecology*, *43*, 119–130. https://doi.org/10.1007/s10745-015-9726-4

Biernacki, C., & Jacques, J. (2013). A generative model for rank data based on insertion sort algorithm. *Computational Statistics & Data Analysis*, *58*, 162–176. https://doi.org/10.1016/j.csda.2012.08.008

Brandt, R., Mathez-Stiefel, S. L., Lachmuth, S., Hensen, I., & Rist, S. (2013). Knowledge and valuation of Andean agroforestry species: The role of sex, age, and migration among members of a rural community in Bolivia. *Journal of Ethnobiology and Ethnomedicine*, *9*, 83. https://doi.org/10.1186/1746-4269-9-83

Bukomeko, H., Jassogne, L., Kagezi, G. H., Mukasa, D., & Vaast, P. (2018). Influence of shaded systems on Xylosandrus compactus infestation in Robusta coffee along a rainfall gradient in Uganda. *Agricultural and Forest Entomology*, *20*, 327–333. https://doi.org/10.1111/afe.12265

Bukomeko, H., Jassogne, L., Tumwebaze, S. B., Eilu, G., & Vaast, P. (2019). Integrating local knowledge with tree diversity analyses to optimize on-farm tree species composition for ecosystem service delivery in coffee agroforestry systems of Uganda. *Agroforestry Systems*, *93*, 755–770. https://doi.org/10.1007/s10457-017-0172-8

Carpente, A. (2020). *Optimizing shade tree species recommendation through the mobilization of local ecological knowledge. Experience from the small-scale coffee agroforestry systems in Matagalpa Department, Nicaragua* (p. 166). University of Copenhagen.

Cerdán, C. R., Rebolledo, M. C., Soto, G., Rapidel, B., & Sinclair, F. L. (2012). Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. *Agricultural Systems*, *110*, 119–130. https://doi.org/10.1016/j.agsy.2012.03.014

Charnley, S., Fischer, A. P., & Jones, E. T. (2007). Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. *Forest Ecology and Management*, *246*, 14–28. https://doi.org/10.1016/j.foreco.2007.03.047

Chechina, M., & Hamann, A. (2015). Choosing species for reforestation in diverse forest communities: Social preference versus ecological suitability. *Ecosphere*, *6*, art240. https://doi.org/10.1890/ES15-00131.1

Coe, R., Sinclair, F., & Barrios, E. (2014). Scaling up agroforestry requires research 'in' rather than 'for' development. *Current Opinion in Environmental Sustainability*, *6*, 73–77. https://doi.org/10.1016/j.cosust.2013.10.013

Davis, A., & Wagner, J. R. (2003). Who Knows? On the Importance of Identifying "Experts" When Researching Local Ecological Knowledge. *Human Ecology*, *31*, 463–489. https://doi.org/10.1023/a:1025075923297

deAlbuquerque, U. P. (2006). Re-examining hypotheses concerning the use and knowledge of medicinal plants: A study in the Caatinga vegetation of NE Brazil. *Journal of Ethnobiology and Ethnomedicine*, *2*, 30. https://doi.org/10.1186/1746-4269-2-30

deAlbuquerque, U. P., deSousa Araújo, T. A., Ramos, M. A., doNascimento, V. T., deLucena, R. F. P., Monteiro, J. M., Alencar, N. L., & deLima Araújo, E. (2009). How ethnobotany can aid biodiversity conservation: Reflections on investigations in the semi-arid region of NE Brazil. *Biodiversity and Conservation*, *18*, 127–150. https://doi.org/10.1007/s10531-008-9463-8

Fremout, T., Gutiérrez-Miranda, C. E., Briers, S., Marcelo-Peña, J. L., Cueva-Ortiz, E., Linares-Palomino, R., La Torre-Cuadros, M. d.l. Á., Chang-Ruíz, J. C., Villegas-Gómez, T. L., Acosta-Flota, A. H., Plouvier, D., Atkinson, R., Charcape-Ravelo, M., Aguirre-Mendoza, Z., Muys, B., & Thomas, E. (2021). The value of local ecological knowledge to guide tree species selection in tropical dry forest restoration. *Restoration Ecology*, *29*, e13347. https://doi.org/10.1111/rec.13347

Fremout, T., Thomas, E., Taedoumg, H., Briers, S., Gutiérrez-Miranda, C. E., Alcázar-Caicedo, C., Lindau, A., Mounmemi Kpoumie, H., Vinceti, B., Kettle, C., Ekué, M., Atkinson, R., Jalonen, R., Gaisberger, H., Elliott, S., Brechbühler, E., Ceccarelli, V., Krishnan, S., Vacik, H., … Muys, B. (2022). Diversity for Restoration (D4R): Guiding the selection of tree species and seed sources for climate-resilient restoration of tropical forest landscapes. *Journal of Applied Ecology*, *59*, 664–679. https://doi.org/10.1111/1365-2664.14079

Funk, J. L., Larson, J. E., Ames, G. M., Butterfield, B. J., Cavender-Bares, J., Firn, J., Laughlin, D. C., Sutton-Grier, A. E., Williams, L., & Wright, J. (2017). Revisiting the Holy Grail: Using plant functional traits to understand ecological processes. *Biological Reviews*, *92*, 1156–1173. https://doi.org/10.1111/brv.12275

German, L. A., Kidane, B., & Shemdoe, R. (2006). Social and environmental trade-offs in tree species selection: A methodology for identifying niche incompatibilities in agroforestry. *Environment, Development and Sustainability*, *8*, 535–552. https://doi.org/10.1007/s10668-006-9054-3

Gosling, E., & Reith, E. (2020). Capturing farmers' knowledge: Testing the analytic hierarchy process and a ranking and scoring method. *Society & Natural Resources*, *33*, 700–708. https://doi.org/10.1080/08941920.2019.1681569

Graefe, S., Meyer-Sand, L. F., Chauvette, K., Abdulai, I., Jassogne, L., Vaast, P., & Asare, R. (2017). Evaluating farmers' knowledge of shade trees in different cocoa agro-ecological zones in Ghana. *Human Ecology*, *45*, 321–332. https://doi.org/10.1007/s10745-017-9899-0

Gram, G., Vaast, P., van derWolf, J., & Jassogne, L. (2017). Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in Mount Elgon, Uganda. *Agroforestry Systems*, *92*, 1625–1638. https://doi.org/10.1007/s10457-017-0111-8

Guillemot, J., leMaire, G., Munishamappa, M., Charbonnier, F., & Vaast, P. (2018). Native coffee agroforestry in the Western Ghats of India maintains higher carbon storage and tree diversity compared to exotic agroforestry. *Agriculture, Ecosystems & Environment*, *265*, 461–469. https://doi.org/10.1016/j.agee.2018.06.002

Hastings, Z., Ticktin, T., Botelho, M., Reppun, N., Kukea-Shultz, K., Wong, M., Melone, A., & Bremer, L. (2020). Integrating co-production and functional trait approaches for inclusive and scalable restoration solutions. *Conservation Science and Practice*, *2*, e250. https://doi.org/10.1111/csp2.250

Hundera, K. (2016). Shade tree selection and management by farmers in traditional coffee production systems in south west Ethiopia. *Ethiopian Journal of education and sciences*, *11*, 91–103.

Jagoret, P., Michel-Dounias, I., Snoeck, D., Ngnogué, H. T., & Malézieux, E. (2012). Afforestation of savannah with cocoa agroforestry systems: A small-farmer innovation in central Cameroon. *Agroforestry Systems*, *86*, 493–504. https://doi.org/10.1007/s10457-012-9513-9

Jassogne, L., vanAsten, P. J. A., & Wanyama, I. B. (2012). Perceptions and outlook on intercropping coffee with banana as an opportunity for smallholder coffee farmers in Uganda. *International Journal of Agricultural Sustainability*, *11*, 144–158. https://doi.org/10.1080/14735903.2012.714576

Jerneck, A., & Olsson, L. (2013). More than trees! Understanding the agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya. *Journal of Rural Studies*, *32*, 114–125. https://doi.org/10.1016/j.jrurstud.2013.04.004

Jezeer, R. E., Santos, M. J., Boot, R. G. A., Junginger, M., & Verweij, P. A. (2018). Effects of shade and input management on economic performance of small-scale Peruvian coffee systems. *Agricultural Systems*, *162*, 179–190. https://doi.org/10.1016/j.agsy.2018.01.014

Kenny, U., Regan, Á., Hearne, D., & O'Meara, C. (2021). Empathising, defining and ideating with the farming community to develop a geotagged photo app for smart devices: A design thinking approach. *Agricultural Systems*, *194*, 103248. https://doi.org/10.1016/j.agsy.2021.103248

Lake, F., Parrotta, J., Giardina, C., Davidson-Hunt, I., & Uprety, Y. (2018). Integration of Traditional and Western knowledge in forest landscape restoration. In: Mansourian, S., & Parrotta, J., (Eds.), *Forest Landscape Restoration: Integrated approaches to support effective implementation*. (pp. 198–226). Routledge.

Lamond, G., Sandbrook, L., Gassner, A., & Sinclair, F. L. (2016). Local knowledge of tree attributes underpins species selection on coffee farms. *Experimental Agriculture*, *55*, 1–15. https://doi.org/10.1017/S0014479716000168

Lépine, M. (2018). *Connaissances locales des services écosystémiques dans les systèmes agroforestiers à base de caféiers au Laos* (p. 119). ISTOM.

Liebig, T., Jassogne, L., Rahn, E., Läderach, P., Poehling, H.-M., Kucel, P., Van Asten, P., & Avelino, J. (2016). Towards a Collaborative Research: A Case Study on Linking Science to Farmers' Perceptions and Knowledge on Arabica Coffee Pests and Diseases and Its Management. *PLoS ONE*, *11*, e0159392. https://doi.org/10.1371/journal.pone.0159392

Lunelli, N. P., Ramos, M. A., & Oliveira Júnior, C. J. F. D. (2016). Do gender and age influence agroforestry farmers' knowledge of tree species uses in an area of the Atlantic Forest, Brazil? *Acta Botanica Brasilica*, *30*(4), 667–682.

Mariel, J., Carrière, S. M., Penot, E., Danthu, P., Rafidison, V., & Labeyrie, V. (2021). Exploring farmers' agrobiodiversity management practices and knowledge in clove agroforests of Madagascar. *People and Nature*, *3*, 914–928. https://doi.org/10.1002/pan3.10238

Mathez-Stiefel, S.-L., Brandt, R., Lachmuth, S., & Rist, S. (2012). Are the young less knowledgeable? Local knowledge of natural remedies and its transformations in the Andean Highlands. *Human Ecology*, *40*, 909–930. https://doi.org/10.1007/s10745-012-9520-5

Meemken, E.-M., Veettil, P. C., & Qaim, M. (2017). Toward improving the design of sustainability standards—A gendered analysis of farmers' preferences. *World Development*, *99*, 285–298. https://doi.org/10.1016/j.worlddev.2017.05.021

Mekoya, A., Oosting, S. J., Fernandez-Rivera, S., & Van der Zijpp, A. J. (2008). Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. *Agroforestry Systems*, *73*, 141–153. https://doi.org/10.1007/s10457-007-9102-5

Mistry, J., & Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science*, *352*, 1274–1275. https://doi.org/10.1126/science.aaf1160

Nath, C. D., Schroth, G., & Burslem, D. F. R. P. (2016). Why do farmers plant more exotic than native trees? A case study from the Western Ghats, India. *Agriculture, Ecosystems & Environment*, *230*, 315–328. https://doi.org/10.1016/j.agee.2016.05.013

Nguyen, M. P., Vaast, P., Pagella, T., & Sinclair, F. (2020). Local knowledge about ecosystem services provided by trees in coffee agroforestry practices in Northwest Vietnam. *Land*, *9*, 486. https://doi.org/10.3390/land9120486

Nijmeijer, A., Lauri, P.-E., Harmand, J.-M., Freschet, G. T., Essobo Nieboukaho, J.-D., Fogang, P. K., Enock, S., & Saj, S. (2019). Long-term dynamics of cocoa agroforestry systems established on lands previously occupied by savannah or forests. *Agriculture, Ecosystems & Environment*, *275*, 100–111. https://doi.org/10.1016/j.agee.2019.02.004

Olsson, P., & Folke, C. (2001). Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken Watershed, Sweden. *Ecosystems*, *4*, 85–104. https://doi.org/10.1007/s100210000061

Rahn, E., Vaast, P., Läderach, P., vanAsten, P., Jassogne, L., & Ghazoul, J. (2018). Exploring adaptation strategies of coffee production to climate change using a process-based model. *Ecological Modelling*, *371*, 76–89. https://doi.org/10.1016/j.ecolmodel.2018.01.009

Reubens, B., Moeremans, C., Poesen, J., Nyssen, J., Tewoldeberhan, S., Franzel, S., Deckers, J., Orwa, C., & Muys, B. (2011). Tree species selection for land rehabilitation in Ethiopia: From fragmented knowledge to an integrated multi-criteria decision approach. *Agroforestry Systems*, *82*, 303–330. https://doi.org/10.1007/s10457-011-9381-8

Rigal, C., Vaast, P., & Xu, J. (2018). Using farmers' local knowledge of tree provision of ecosystem services to strengthen the emergence of coffee-agroforestry landscapes in southwest China. *PLoS One*, *13*, e0204046. https://doi.org/10.1371/journal.pone.0204046

Rigal, C., Xu, J., & Vaast, P. (2019). *Young shade trees improve soil quality in intensively managed coffee systems recently converted to agroforestry in Yunnan Province, China*. Plant and Soil. https://doi.org/10.1007/s11104-019-04004-1

Ruddle, K., & Davis, A. (2013). Local ecological knowledge (LEK) in interdisciplinary research and application: A critical review. *Asian Fisheries Science*, *26*, 79–100. https://doi.org/10.33997/j.afs.2013.26.2.002

Sari, R. R., Saputra, D. D., Hairiah, K., Rozendaal, D., Roshetko, J. M., & Van Noordwijk, M. (2020). Gendered species preferences link tree diversity and carbon stocks in cacao agroforest in Southeast Sulawesi, Indonesia. *Land*, *9*(4), 108. https://doi.org/10.3390/land9040108

Sinclair, F. L., & Walker, D. H. (1998). Acquiring qualitative knowledge about complex agroecosystems. Part 1: Representation as natural language. *Agricultural Systems*, *56*, 341–363. https://doi.org/10.1016/S0308-521X(97)00048-6

Smith Dumont, E., Bonhomme, S., Pagella, T. F., & Sinclair, F. L. (2019). Structured stakeholder engagement leads to development of more diverse and inclusive agroforestry options. *Experimental Agriculture*, *55*, 252–274. https://doi.org/10.1017/S0014479716000788

Smith Dumont, E., Gassner, A., Agaba, G., Nansamba, R., & Sinclair, F. (2018). The utility of farmer ranking of tree attributes for selecting companion trees in coffee production systems. *Agroforestry Systems*, *93*, 1469–1483. https://doi.org/10.1007/s10457-018-0257-z

Smith Dumont, E., Gnahoua, G. M., Ohouo, L., Sinclair, F. L., & Vaast, P. (2014). Farmers in Côte D'ivoire value integrating tree diversity in cocoa for the provision of ecosystem services. *Agroforestry Systems*, *88*, 1047–1066. https://doi.org/10.1007/s10457-014-9679-4

Suárez, A., Williams-Linera, G., Trejo, C., Valdez-Hernández, J. I., Cetina-Alcalá, V. M., & Vibrans, H. (2012). Local knowledge helps select species for forest restoration in a tropical dry forest of central Veracruz, Mexico. *Agroforestry Systems*, *85*, 35–55. https://doi.org/10.1007/s10457-011-9437-9

Tebboth, M. G. L., Few, R., Assen, M., & Degefu, M. A. (2020). Valuing local perspectives on invasive species management: Moving beyond the ecosystem service-disservice dichotomy. *Ecosystem Services*, *42*, 101068. https://doi.org/10.1016/j.ecoser.2020.101068

Thomas, E., Vandebroek, I., & Van Damme, P. (2007). What works in the field? A comparison of different interviewing methods in Ethnobotany with special reference to the use of photographs. *Economic Botany*, *61*, 376–384. https://doi.org/10.1663/0013-0001(2007)61[376:WWITFA]2.0.CO;2

Tscharntke, T., Clough, Y., Bhagwat, S. A., Buchori, D., Faust, H., Hertel, D., Hölscher, D., Juhrbandt, J., Kessler, M., Perfecto, I., Scherber, C., Schroth, G., Veldkamp, E., & Wanger, T. C. (2011). Multifunctional shade-tree management in tropical agroforestry landscapes – A review. *Journal of Applied Ecology*, *48*, 619–629. https://doi.org/10.1111/j.1365-2664.2010.01939.x

Tully, K. L., & Lawrence, D. (2012). Canopy and leaf composition drive patterns of nutrient release from pruning residues in a coffee agroforest. *Ecological Applications*, *22*, 1330–1344. https://doi.org/10.1890/10-2342.1

Turner, H., Firth, D. (2012). Bradley-Terry models in R: The BradleyTerry2 package. p. 21. 10.18637/jss.v048.i09

Turner, H. L., vanEtten, J., Firth, D., & Kosmidis, I. (2020). Modelling rankings in R: The PlackettLuce package. *Computational Statistics*, *35*, 1027–1057. https://doi.org/10.1007/s00180-020-00959-3

Tusznio, J., Pietrzyk-Kaszyńska, A., Rechciński, M., Olszańska, A., & Grodzińska-Jurczak, M. (2020). Application of the ecosystem services concept at the local level – Challenges, opportunities, and limitations. *Ecosystem Services*, *42*, 101077. https://doi.org/10.1016/j.ecoser.2020.101077

Uprety, Y., Asselin, H., Bergeron, Y., Doyon, F., & Boucher, J.-F. (2012). Contribution of traditional knowledge to ecological restoration: Practices and applications. *Écoscience*, *19*, 225–237. https://doi.org/10.2980/19-3-3530

Vaast, P., Beer, J., Harvey, C., & Harmand, J. M. (2005). Environmental services of coffee agroforestry systems in central america: A promising potential to improve the livelihoods of coffee farmers' communities. Integrated management of environmental services in human-dominated tropical landscapes (pp. 35–39). Retrieved from http://repositorio.bibliotecaorton.catie.ac.cr/handle/11554/2565

Valencia, V., West, P., Sterling, E. J., García-Barrios, L., & Naeem, S. (2015). The use of farmers' knowledge in coffee agroforestry management: Implications for the conservation of tree biodiversity. *Ecosphere*, *6*, 1–17. https://doi.org/10.1890/ES14-00428.1

van derWolf, J., Jassogne, L., Gram, G., & Vaast, P. (2016). Turning local knowledge on agroforestry into an online decision-support tool for tree selection in Smallholders' Farms. *Experimental Agriculture*, *55*, 50–66. https://doi.org/10.1017/S001447971600017X

Wagner, S., Rigal, C., Liebig, T., Mremi, R., Hemp, A., Jones, M., Price, E., & Preziosi, R. (2019). Ecosystem services and importance of common tree species in coffee-agroforestry systems: Local knowledge of small-scale farmers at Mt. Kilimanjaro, Tanzania. *Forests*, *10*, 963. https://doi.org/10.3390/f10110963

Yuan, Z., Lun, F., He, L., Cao, Z., Min, Q., Bai, Y., Liu, M., Cheng, S., Li, W., & Fuller, A. (2014). Exploring the state of retention of traditional ecological knowledge (TEK) in a Hani Rice Terrace Village, Southwest China. *Sustainability*, *6*, 4497. https://doi.org/10.3390/su6074497

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