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Ecosystem Services and Importance of Common Tree Species in Coffee-Agroforestry Systems: Local Knowledge of Small-Scale Farmers at Mt. Kilimanjaro, Tanzania

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Abstract: *Research Highlights:* Global coffee production, especially in smallholder farming systems, is vulnerable and must adapt in the face of climate change. To this end, shaded agroforestry systems are a promising strategy. *Background and Objectives:* Understanding local contexts is a prerequisite for designing locally tailored systems; this can be achieved by utilizing farmers' knowledge. Our objective is to explore ecosystem services (ESs) provided by different shade tree species as perceived by farmers and possible factors (elevation, gender, and membership in local farmers groups) influencing these perceptions. We related these factors, as well as farmers' ESs preferences, to planting densities of tree species. *Materials and Methods:* During interviews with 263 small-scale coffee farmers on the southern slope of Mt. Kilimanjaro, they ranked the most common shade tree species according to perceived provision of the locally most important ESs for coffee farmers. We asked them to estimate the population of each tree species on their coffee fields and to identify the three ESs most important for their household. *Results:* Food, fodder, and fuelwood emerged as the most important ESs, with 37.8% of the respondents mentioning all three as priorities. Density of tree species perceived to provide these three ESs were significantly higher for farmers prioritizing these services compared to farmers that did not consider all three ESs in their top three. *Albizia schimperiana* scored the highest for all rankings of regulatory ESs such as coffee yield improvement, quality shade provision, and soil fertility improvement. Influence of elevation, gender, and farmer group affiliation was negligible for all rankings. *Conclusions:* This study shows the need to understand factors underlying farmers' management decisions before recommending shade tree species. Our results led to the upgrade of the online tool (shadetreeadvice.org) which generates lists of potential common shade tree species tailored to local ecological context considering individual farmers' needs.

Keywords: shade tree species; farmers' knowledge; East Africa

1. Introduction

Agroforestry is a promising agricultural production system due to its potential for climate change mitigation and adaptation [1–3]. Besides carbon sequestration [4], shade trees also improve local climatic conditions and reduce variability in microclimate and soil moisture [1]. Agroforestry is particularly important for coffee (*Coffea arabica* L.) production as climate change is expected to reduce the suitable production area for crops such as coffee [5–7]. In addition to regulatory services, the associated shade tree species can provide various direct ecosystem services (ESs) such as food, fodder, or fuelwood [8]. Furthermore, due to their diversity, agroforestry systems have the potential to provide diverse income sources which may act as social safety nets, increasing farmers' economic resilience in the face of coffee price volatility in global markets and possible crop failures [8–11]. However, ecological conditions, competition among associated species in the system, and farmers' individual objectives need to be considered in designing agroforestry systems to maximize the benefits and minimize the shortcomings of these systems [12,13].

Farmers can be very knowledgeable on factors that influence coffee productivity. From experience, they are aware of interaction(s) between shade tree species and coffee, as well as many direct ESs provided by specific tree species [14,15]. In some areas, however (e.g., the impact of individual tree species on pests and diseases), their knowledge might be limited [16–18]. Nevertheless, exploring farmers' knowledge might provide novel insights into interactions between shade tree species and coffee productivity. This local knowledge is vital in tailoring recommendations to local conditions.

Although several studies have investigated how the Chagga people living on Mt. Kilimanjaro in Tanzania use their natural environment [19–22], research has so far not identified which tree species are considered superior in providing relevant ESs for the local coffee farmers. Our aim is to assess indigenous knowledge of local farmers on Mt. Kilimanjaro regarding selection of shade trees that enhance coffee production and provide other ESs. A participatory approach based on van der Wolf et al. [23] allowed us to collect and study farmers' knowledge regarding shade tree species' provision of ESs. Following this approach, we identified shade tree species with high potential for coffee agroforestry systems on the southern slopes of Mt. Kilimanjaro. Similar studies have been conducted in other East African countries and the differences in findings [15,16,24,25] demonstrate the importance of locally specific investigations.

In this study, we explore the ESs provided by different shade tree species as perceived by farmers. We further examine if elevation, gender, and membership in local farmers' groups influence the perceived ESs provided, and the planting density of different shade tree species. Farm management may be based on farmers' knowledge and preference for specific shade tree species [15]. Therefore, we expect that the planting density of tree species will depend on the perceived ESs the tree species provides, as well as farmers' ESs preference.

The study aims to contribute to expanding the database of the online decision-support tool for tree selection in smallholder farming systems (shadetreeadvice.org) [23] and help tailor recommendations for important shade tree species for coffee farmers on Mt. Kilimanjaro.

2. Materials and Methods

2.1. Study Site

The research took place on the southern slopes of Mt. Kilimanjaro in Tanzania (Latitude 3°13′9″ S–3°17′41″ S; Longitude 37°9′24″ E–37°25′19″ E) (Figure 1). Here, the Chagga people have cultivated and converted the former forest into an agroforestry system (the so-called Chagga homegardens) over several centuries [21]. The main cultivation zone of *C. arabica* in these traditional coffee-banana plantations is located between 1000 m and 1800 m asl [26] and covers an area of nearly 80,000 ha [27]. Kilimanjaro National Park prevents expansion of coffee cultivation into higher elevations [19]. For our study area, Hemp [26] reports annual rainfall in the lower slopes (800 m to 1300 m asl) of between

900 mm to 1580 mm, and 1580 mm to 2200 mm at the higher slopes (1300 m to 1800 m asl) and mean annual temperatures of 23.4 to 18.8 °C and 18.8 to 16.1 °C, respectively.

Coffee farmers from eight communities participated in this study. Six communities work with the non-government organization Hanns R. Neumann Stiftung (HRNS) (Isuki, Lemira Mroma, Masama Mula, Mudio, Kiwakabo, and Mbokomu); two communities have no connection to the HRNS, are located in the center of the southern slope (Narum and Mweka), and were included in the study to have a wider representation of the study area (Figure 1).

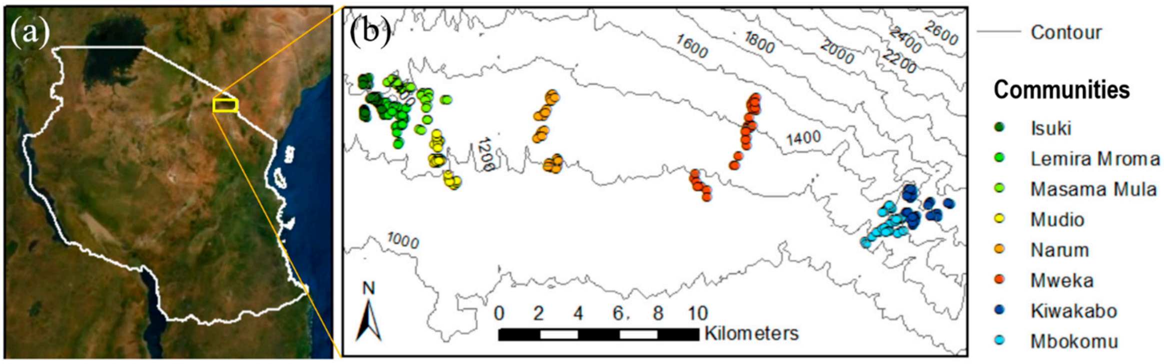

Figure 1. Location of the research area within Tanzania (**a**) and the distribution of the respondents along the southern slope of Mt. Kilimanjaro, divided into the eight communities (**b**).

2.2. *Identification of Common Tree Species and Important Ecosystem Services*

To identify the most common tree species and most important ESs for coffee farmers of the study area for subsequent data collection, we conducted focus group discussions (FGDs) [28]. In March 2019, we conducted three FGDs in the west (Isuki, Masama Mula and Mudio) and two FGDs in the east (Kiwakabo and Mbokomo). Participants were coffee farmers representing farmers' groups and independent farmers from the same community. Each FGD had between 9 and 15 attendees, leading to a total of 56 attendees.

The list of tree species that participants could choose from was based on Hemp [26], and the results of an investigation of 40 plots of Chagga homegardens in Narum and Mweka (unpublished data). As small-scale farmers in this region commonly intercropped coffee and banana (*Musa* spp.), we included the latter as a shade species. This resulted in an initial list of 58 shade tree species. We prepared technical sheets for each shade tree species showing pictures of the plant or plant parts, as well as the local name. We presented these sheets to the focus groups and asked them to rank the shade tree species according to their frequency in coffee fields in their area. Tree species shown to each FGD were then added or removed from the presented list of trees based on their rankings during previous FDGs. In subsequent data collection interviews with individual farmers, we only used the most common shade tree species. This list was composed of 22 tree species that were either ranked in the top 20 in at least three FGDs or in the top 10 of any single FGD (see the species listed in Table S1).

For identification of the locally most important ESs for farmers, we presented 25 ESs to the focus groups and asked the participants to add any additional ESs they considered important. The groups then ranked the services according to their perceived importance, giving us the final list of the 12 locally most important ESs for subsequent data collection interviews. The list included nine ESs that were ranked in the top 12 of at least four FGDs (food provision, shade provision, protection against wind, protection from heat, fodder supply, mulch provision, increased coffee yield, soil fertility improvement, and weed suppression); one ES ranked number four in one FGD and in the top 10 of two other FGDs (increasing coffee quality); one ES ranked as number two in two FGDs, but below 10 in all other FGDs (firewood supply); and one ES ranked as number one in one FGD, but only in the top 10 in one other FGD (soil moisture enhancement) (see all ESs listed in Table S2).

2.3. Shade Tree Species Ranking for Ecosystem Services

Ranking the most common tree species according to the most important ESs was the focus of data collection interviews with 263 small-scale coffee farmers along the southern slope of Mt. Kilimanjaro (Figure 1). In March and April 2019, we conducted at least 30 individual interviews in each community (Figure 1). We began with farmers that participated in the FGDs or whose farm we investigated; we then interviewed occupants of the fifth house away in each direction along the road. If the person in the fifth house was not a coffee farmer, declined participation, or was absent at the time, we asked at the next house(s) until a respondent was identified.

The respondents were asked to select the 10 tree species that they knew best out of the list of 22 most common shade tree species [23]. They were then asked to rank the 10 chosen shade tree species for each of the 12 locally most important ESs from the best (high provision of this ES) to the least performing (low provision of this ES) [16,23]. We also recorded gender, membership of the HRNS, and elevation of the respondents' home (using a GARMIN GPSMAP 64). We asked the respondents to name the three most important ESs for their household and the estimated number of individuals of the different tree species they had on their coffee fields, as well as the size of their coffee farm.

2.4. Data Analysis

We noted the number of tree species each farmer had of the 22 most common shade tree species, the percentage of farmers having each tree species in their fields, and the planting density of each tree species, using farmers' estimated number of trees and farm size. To identify the influence of elevation on the tree planting density of different tree species, we did linear regressions for each common shade tree species in R 3.5.0 [29]. We summarized the ESs respondents considered most important and tested gender differences with a chi-square test in R 3.5.0 [29].

Based on the method of van der Wolf, et al. [23], we used the BradleyTerry2 package in R 3.5.0 [29] to identify shade tree species best at providing specific ESs, as perceived by the farmers. We excluded interview respondents with less than five years of experience as well as tree species that were ranked less than 10 times for a particular ESs [18]; this left 20 of the 22 tree species in the analysis. As explained by Rigal el al. [18], the ranks for each ESs need to be converted into pairwise comparisons to fit the Bradley-Terry model. For each tree species and ES, this model calculates scores, which are comparative values representing the likelihood that one tree species performs better than another tree species in providing an ES [18]. We normalized the scores between 0 and 1 to be able to compare them [18]. Besides the scores, quasi-standard errors were calculated to indicate how frequently a species was included in the ranking and how consistently the respondents ranked this species [18]. We compared the scores pairwise using a Wald test. The more pairs that are significantly different, the more it reflects an agreement of farmers upon the ranking of the tree species. Therefore, large numbers of pairs that are significantly different indicate that the analysis is robust [18]. In our results, the lowest percent of pairs that were different was 67%, and the highest was 89%.

To assess the influence of farmers' objectives on their management practices, we compared shade tree densities on coffee farms between groups of farmers with different sets of priorities. More specifically, we split respondents into two groups: those who had selected the combination of the three most important ESs for small-scale coffee farmer households at Mt. Kilimanjaro as their top three priorities and those who had not. We then compared the shade tree density of species perceived to perform high for the combination of these ESs and tested differences between the two farmer groups using t-tests in R 3.5.0 [29].

To identify if gender, affiliation to a farmers' group, or elevation influenced perceived provision of ESs by shade tree species, we split the data sets by gender, membership of the HRNS, and into two elevation groups (threshold was the median 1336 m asl). We ran the BradleyTerry analysis for these subgroups of respondents and compared the resulting scores [15,16].

2.5. Ethical Approval

Ethical approval for this study was obtained from the Faculty Research Ethics and Governance Committees of the Manchester Metropolitan University, Faculty of Science and Engineering, on 26 May 2017, with application code SE1617108C.

3. Results

3.1. Main Characteristics of Respondent

Of the total respondents, 96 were women (36.5%) and 167 men (63.5%). The farm size ranged between 0.1 and 8 ha, the average farm size was 0.7 ha with 83.3% (219 respondents) having less than 1 ha. The elevation ranged from 1148 m to 1748 m asl, with an average elevation of 1343 m asl and a median elevation of 1336 m asl (Figure 2). Ninety-seven respondents (37%) were members of the HRNS, while 166 were non-members (63%).

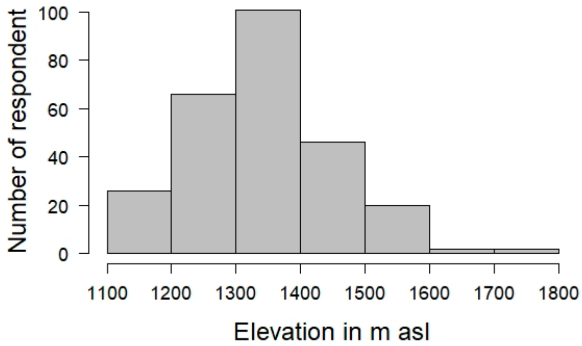

Figure 2. Distribution of respondents along elevation.

3.2. Tree Species Distribution

Sixty percent of the farmers reported that they had 10 or more of the 22 most common shade tree species on their coffee farms. The most common shade tree species is *Musa* spp. grown by all respondents, followed by *Grevillea robusta* A. Cunn. ex R. Br., *Albizia schimperiana* Oliv., and *Persea americana* Miller with 94.3%, 90.9%, and 83.7%, respectively (Figure 3). *Musa* spp. is by far the shade species with the highest density (1089 ± 106 tree ha^{-1}) (Figure 3). *Grevillea robusta* is second densest (39.1 ± 3.29 tree ha^{-1}), closely followed by *Markhamia lutea* (Benth.) K. Schum. (26.6 ± 4.90 tree ha^{-1}). Just a few farmers (about 20 percent) grow *M. lutea*. However, those that do grow it have a high density of the species on their fields. Despite their presence on more than 83% of coffee farms, the densities of *A. schimperiana* (7.9 ± 0.46 tree ha^{-1}) and *P. americana* (12.3±0.98 tree ha^{-1}) are significantly lower than those of the above species (Figure 3).

Neither the total shade tree density nor the *Musa* spp. density are significantly influenced by elevation. However, we observed differences in density of some tree species. Linear regressions show significant reduction in densities of *Cordia africana* Lam. ($F_{(1,261)} = 12.91$, $p < 0.001$), *Mangifera indica* L. ($F_{(1,261)} = 5.03$, $p = 0.026$) and *Senna siamea* (Lam.) H. S. Irwin & Barneby ($F_{(1,261)} = 3.96$, $p = 0.048$) with increasing elevation—the densities are reduced by 1.1 tree ha^{-1}, 0.4 tree ha^{-1} and 0.3 tree ha^{-1} respectively for every 100 m increase. We detected a significant increase in density towards higher elevations for *Margaritaria discoidea* (Baill.) G. L. Webster ($F_{(1,261)} = 30.88$, $p < 0.001$) and *P. americana* ($F_{(1,261)} = 11.77$, $p < 0.001$) (with an increase of 100 m, the density increases by 2.4 tree ha^{-1} and 2.7 tree ha^{-1} respectively).

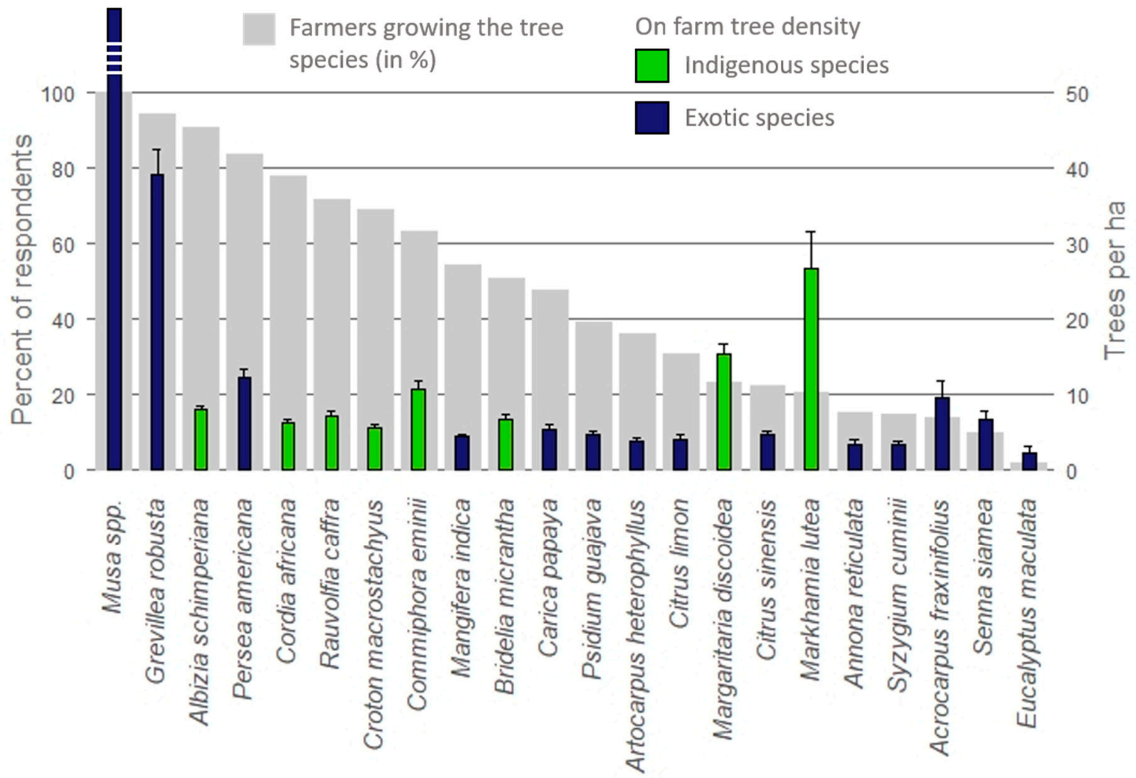

Figure 3. Percent of respondents reporting each species on their farm and average (+SE) tree density on those farms. The density of *Musa* spp. is much higher than the scale shown in the graph (1089 trees per ha on average).

3.3. Important Ecosystem Services

On the southern slope of Mt. Kilimanjaro, food provisioning is by far the most essential ES for coffee farmers. Of the 263 respondents, more than 75% selected food provision as the most important ES for their household, and more than 95% ranked it in the top three (Table 1). The second locally most important ESs is fuelwood supply, which was ranked first by 10% of the respondents and within the top three ESs by nearly 60% of the respondents (Table 1). More than 50% of the respondents also ranked fodder supply among the top three ESs, followed by shade provision, soil fertility improvement and increased coffee yield (Table 1). A chi-square test showed no significant differences in ES preference between genders. The only significant difference between the two elevation groups was that respondents at a higher elevation included soil moisture enhancement more often in the top three ESs than respondents at lower elevation (4.4% and 1.0% respectively, $X^2 = 7.2$, $p < 0.01$).

3.4. Pairwise Comparison

The analysis shows that the ranking of shade tree species is consistent for most ESs. We observed the clearest discrimination between tree species in the ranking for mulch provision and protection from heat with 89.1% and 87.9% of the pairwise comparisons of tree species' scores being significantly different ($p < 0.05$), followed by increase in coffee yield and quality (Table 2). Most difficult to rank were weed suppression, food provision, and protection against wind with 66.7%, 71.1%, and 72.5% of all pairs being significantly different ($p < 0.05$) (Table 2).

Table 1. Ranking of Ecosystem services on a household level.

Ecosystem Services (ESs)	Selected as First ES	Among the First 3 ESs
Food provision	76.4%	95.4%
Firewood supply	10.3%	59.5%
Fodder supply	2.7%	55.3%
Shade provision	3.4%	31.7%
Soil fertility improvement	2.7%	17.2%
Increased coffee yield	0.0%	15.6%
Soil moisture enhancement	1.5%	8.0%
Increased coffee quality	0.8%	5.7%
Protection against wind	1.1%	5.3%
Mulch provision	0.8%	3.4%
Protection from heat	0.0%	1.5%
Weed suppression	0.4%	1.1%

Table 2. Percent of significantly different pairwise comparisons of species' scores.

Ecosystem Service	Number of Tree Species Included in the Ranking	Percent of Significant Differences between Pairs ($p < 0.05$)
Mulch provision	11	89.1
Protection from heat	12	87.9
Increased coffee yield	11	87.3
Increased coffee quality	10	86.7
Soil moisture enhancement	11	85.5
Shade provision	12	84.8
Fodder supply	11	83.6
Firewood supply	13	82.1
Soil fertility improvement	13	76.9
Protection against wind	16	72.5
Food provision	10	71.1
Weed suppression	13	66.7

3.5. Tree Ranking

Scores of the tree species ranked according to the three most important ESs for small-scale coffee farmers at the southern slopes of Mt. Kilimanjaro show major differences (Figure 4). Of the most common tree species providing food, all are exotic. Firewood is mainly obtained from indigenous species, except for *G. robusta*, which is exotic.

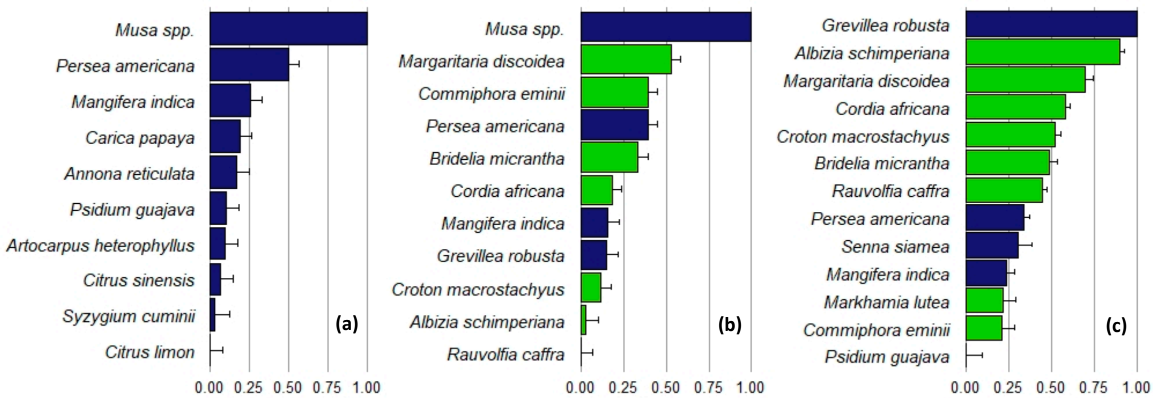

Figure 4. Scores and quasi-standard errors of tree species for (**a**) food provision, (**b**) fodder supply and (**c**) firewood supply. Dark blue bars represent exotic, and green bars indigenous tree species.

For a better recommendation of tree species regarding multiple regulatory ESs associated with coffee production, the following ESs were combined into three categories: (**a**) coffee production enhancement (combining increase in coffee yield and quality), (**b**) protection from climatic hazards (combining protection from heat, wind and shade provision), (**c**) soil quality enhancement (combining mulch provision, soil fertility and soil moisture enhancement). For each ES category, the scores of shade tree species were averaged over the set of combined ESs (Figure 5).

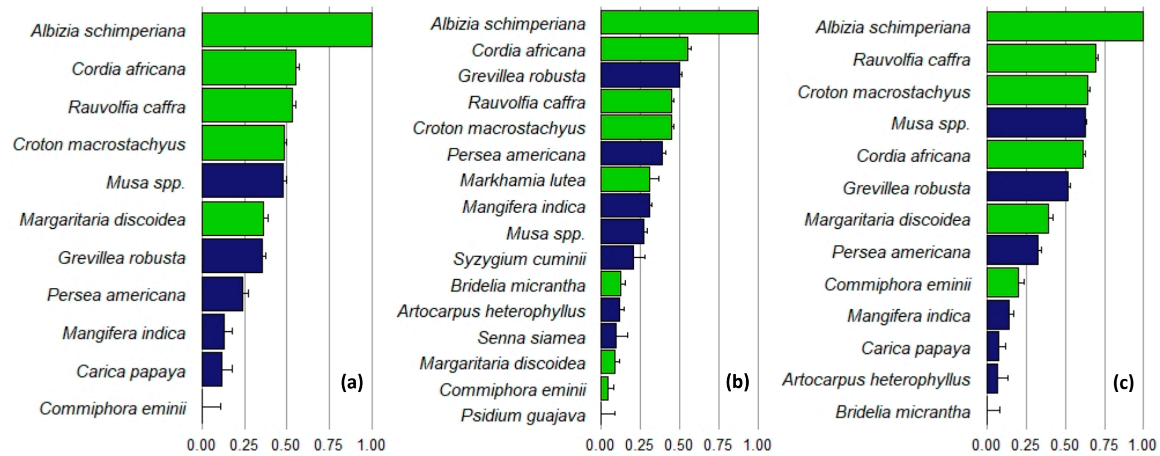

Figure 5. Scores and quasi-standard errors of the tree species ranked according to: (**a**) increase of coffee yield and quality, (**b**) protection from heat, wind and shade provision and (**c**) mulch provision, soil fertility and soil moisture enhancement. Green bars represent indigenous, and dark blue bars exotic tree species.

Albizia schimperiana is the highest ranked tree species for all three ES categories. Also within the top five for all three ES categories are *C. africana*, *Croton macrostachyus* Hochst. ex Delile, and *Rauvolfia caffra* Sond.. All of these tree species are indigenous. *Musa* spp. is important for coffee yield and quality, as well as for soil enhancement, while *G. robusta* contributes to protection from climatic hazards and soil quality enhancement.

3.6. *Effect of Priorites on Shade Tree Density*

Food, fodder, and firewood are the most important ESs for small-scale coffee farmer households (99 respondents (37.8%) selected this combination). To assess the influence ES priorities have on tree species selection, we averaged the scores of each shade tree species for the combination of these three ESs and compared the density of the five best performing tree species between two groups: respondents that selected these three ESs as most important versus those that did not. The planting density of three of these five tree species is significantly higher (t-test, $p < 0.05$) for respondents that selected these ESs as most important compared to those that did not (Figure 6). We found differences for exotic, but not indigenous species.

3.7. *Elevation, Gender, and Farmer Group Affiliation*

The ranking in higher elevations was not significantly different from the lower elevations. The only deviation we observed is that *M. indica* was included in the ranking of shade tree species providing fodder for the lower elevations, while *R. caffra* was included in the higher elevations (Figure S1). Farmers did, however, rank both of these tree species low for this ES.

There were slight differences considering gender and affiliation to a farmers group of the HRNS. Women included *Annona reticulata* L. in their ranking for food provision, and they ranked *Musa* spp. significantly higher for shade provision and soil fertility compared to men. Men ranked *G. robusta* significantly higher for shade provision, while *R. caffra* was ranked higher for soil fertility (Figure S2). Respondents that were members of HRNS ranked *M. discoidea* significantly higher than non-members for protection from heat (Figure S3). For coffee quality, members of HRNS ranked *C. macrostachyus* significantly higher and *Musa* spp. significantly lower than non-members (Figure S3).

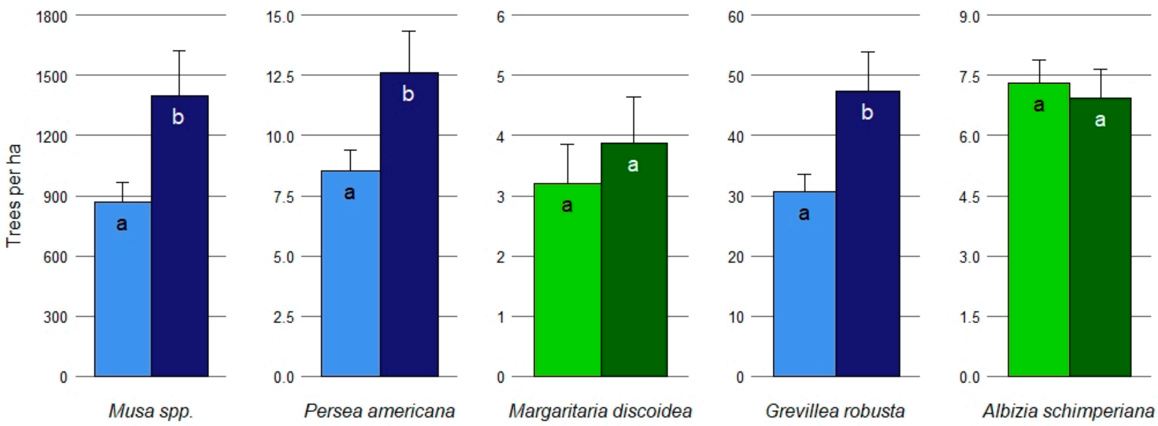

Figure 6. Average (+SE) plant density of the five highest ranked tree species providing the services food, fodder and firewood. The dark bars show respondents who selected the three ESs as the three most important for their family, while the light bars indicate the plant density for respondents who did not select all three. Significant difference between plant density is shown by difference in letters (a and b) ($p < 0.05$). Blue bars represent exotic, and green bars indigenous species.

4. Discussion

4.1. Improtant Ecosystem Services

Nearly all the farmers in our study area considered food provision by shade trees their top priority, followed by the provisioning services fodder and fuelwood supply (Table 1). These ESs were considered more important than regulatory services for coffee production such as shade provision, soil fertility improvement, and increased coffee yield. ES priorities were not significantly different between genders. Respondents of other studies have various priorities. At Mt. Elgon (Uganda), farmers rather prioritized ESs such as mulch provision, erosion control and temperature regulation [16], coffee yield, soil moisture enhancement, and quick leaf decomposition in Central Uganda [24]. Differences in the importance of ESs may reflect differences in environmental conditions, as well as market access [16,30]. One reason participants of the FGDs mentioned for excluding timber from the list of important ESs was the political limitation of tree harvesting [31]. The complexity of agroforestry systems and diverse interactions between different pests and predators on a land-scale level [32–35] might be the reason coffee farmers at Mt. Kilimanjaro did not observe any effect of shade tree species on pests and did not consider it an important ESs provided by shade trees.

4.2. Highly Ranked Tree Species

Albizia schimperiana is the most important shade tree species for coffee production on the southern slope of Mt. Kilimanjaro for the provision of most ESs included in this study. Several studies also report the importance of *A. schimperiana* for coffee production in Ethiopia [36–38]. As a leguminous plant, *A. schimperiana* can form a symbiotic relationship with rhizobia bacteria to fix atmospheric nitrogen, resulting in increased soil fertility. Other studies also show that, with an open wide-spreading crown, *A. schimperiana* provides good shade cover for coffee production, leading to improved microclimate and coffee yield [26,39]. Another advantage of *A. schimperiana* is that its leaves emerge in the dry season [36]. This means it can provide shade when there is a lot of sun and prevents coffee from being too densely shaded during the rainy season.

Despite the benefits of *A. schimperiana* and the perceived provision of multiple regulatory ESs by coffee farmers at Mt. Kilimanjaro, other tree species occurred at a much higher density (Figure 3). From general observations, it seems that the farms have mostly mature trees and that a new generation of *A. schimperiana* is missing. More research on the population structure of *A. schimperiana* in this area is required to get a better understanding of future development and challenges. Belay, et al. [36] found for their study region in Ethiopia that the population structure of *A. schimperiana* had a U-shape with more stems in lower and higher diameter classes, showing selective cutting or extraction of medium sized individuals. Potential explanations could be the increased exploitation of *A. schimperiana* for timber and fuelwood, and its low growth rate [37,40]. Other important aspects to examine are natural regeneration and the success of propagation.

A closely related species that commercial coffee plantations commonly include in their fields is *Albizia gummifera* (J. F. Gmel.) C. A. Sm. This species is favored by farmers in Ethiopia [41,42]. Other *Albizia* species are considered important for providing multiple ESs in East Africa, such as, but not limited to, mulch, shade, improvement of microclimate, coffee yield and soil moisture in Uganda [16,24]. Unfortunately some *Albizia* species are also alternative hosts for black coffee twig borer in the closely related Robusta coffee (*Coffea canephora* Pierre ex Froehn.) posing a potential risk [23].

The other three shade tree species associated with improvements of conditions for coffee production are also indigenous (*C. africana*, *C. macrostachyus* and *R. caffra*). *Rauvolfia caffra* ranked as an important shade tree species which is in line with other findings from Mt. Kilimanjaro [22,26]. Fernandes, et al. [19] report the potential of *R. caffra* to suppress various coffee pests. Its contribution to the production of traditional banana beer underlines its importance in traditional Chagga homegardens [19,22,40]. *Croton macrostachyus* provides good litter, preserves soil moisture, facilitating high coffee yield and high bean weight [43]. *Cordia africana* is also reported as an essential shade tree in coffee production in Kenya [15], Uganda [16] and Ethiopia [42,44]. Even though Kufa, et al. [39] found high coffee yields under *C. africana*, they also reported the highest yield variations under this tree species. As *C. africana* is a high quality timber tree, the economic value might be a major reason for farmers to grow it [42,43].

Even though the four tree species discussed above (*A. schimperiana*, *C. africana*, *C. macrostachyus*, and *R. caffra*) are multipurpose tree species and considered the best to enhance soil quality, create a suitable environment for coffee production and benefit coffee yield and quality, their densities in coffee farms were lower than that of the exotic fast growing *G. robusta* (Figure 3). In Kenya, native tree species were also considered to provide a healthy environment, but their abundance was low due to their slow growth rate [15]. In Tanzania, another reason for the preference of *G. robusta* might be that the wood can be utilized more easily than for native tree species, as native tree species require a permit to be cut down [31,45].

Farmers' management decisions to plant or remove a certain tree species in their plantations is usually based on their knowledge or tree preference [14,15,46]. We therefore need to look at their ESs priorities as socio-economic factors might influence farmers' choices for on-field composition. Our results confirm that the density of exotic tree species perceived to provide food, fodder and fuelwood are higher when farmers prioritize these ESs (Figure 6). This is especially the case when the tree species are exotic, as their presence in the field is usually due to management rather than natural occurrences. Some other studies also show the importance of shade tree species for coffee production is matched with their planting densities [36,42]. Bukomenko, et al. [24], however, found a mismatch between ESs that are important for respondents and the trees they have on their fields. Graefe, et al. [30] used a similar methodology for cocoa production in Ghana and also reported disparities between higher ranked tree species suitable for cocoa intercropping and their abundance in the northern part of the cocoa belt with marginal conditions for cocoa production. This might be an adaptation strategy to diversify income, since they confirmed our findings for farms in the wetter southern region with optimal cocoa production conditions [30]. The match between shade tree density and prioritized ESs appears to be more consistent with direct short- or mid-term benefits for farmers, such as food, fodder, and firewood supply, rather than regulatory service provisioning, such as climate modification and soil fertility improvement [15]. This becomes evident from the lower density of *A. schimperiana* (the most highly ranked tree species for regulatory services) in comparison to *G. robusta* and *P. americana*, which provide direct outputs like fuelwood and food (Figure 3). Our findings stress the importance of understanding the socio-economic component when investigating tree species distribution.

4.3. Factors Influencing Tree Species Ranking and Distribution

The first factor influencing tree species distribution, as just discussed, is farmers' preference and the ESs they consider important for their household.

In general, there is agreement on the ranking of tree species among small-scale coffee farmers at Mt. Kilimanjaro. We can confirm the finding by Gram, et al. [16] that local knowledge regarding ranking of tree species is gender blind, as there were negligible differences in our study. Besides gender, participation in a farmer group did not influence the ranking. Farmers participating in farmer groups meet regularly, receive trainings and exchange knowledge and therefore might have better access to different information sources. This could have led to ranking differences, as other researchers have shown the influence of promotion activities of certain tree species on the perception and distribution of those species [18,46]. In Kenya, *G. robusta* was considered suitable for intercropping with coffee, despite having similar traits to those of tree species believed to negatively affect coffee production [15]. For example, the root system for both *Eucalyptus* spp. and *G. robusta* are perceived to be wide spreading [15]. This discrepancy in perception of different tree species could be due to promotion activities from extension services [15]. Such biases need to be considered when using local knowledge to inform recommendations.

Some studies report an influence of elevation on the distribution and ranking of tree species in East Africa [16,26]. However, we found that neither the presence nor density of tree species in the coffee fields of small-scale farmers at Mt. Kilimanjaro varied much across elevations for most investigated species. The reason could be that our focus was on the most common tree species that are well known by many farmers rather than the whole natural flora as reported by Hemp [26]. *Mangifera indica* and *S. siamea* are known to grow better at lower elevations [40]; it is therefore not surprising that their density is higher at lower elevations. Rather unexpected is the reduced presence and density of *C. africana* with increased elevation as the suitable range for this tree species in the Kilimanjaro regions is reported to be between 1200 m and 2000 m asl. [40]. We therefore conclude that the density of *C. africana* is influenced by socio-economic factors rather than by environmental factors. In Uganda, *C. africana* was perceived to perform well for all ESs [16] and is therefore found in farms at all elevations. Even though this tree species is also perceived to perform highly for regulatory services at Mt. Kilimanjaro, this was not a priority for most farmers. Food being the highest priority explains the presence of either *M. indica* or *P. americana* in 90% of the coffee farms, and the climatic needs for these two species explain the decrease in density of *M. indica* and the increase of density of *P. americana* along the elevation gradient [40]. Another influencing aspect might be increased distance to markets at higher elevations and therefore increased importance of self-sufficiency to farmers. The increased density of *M. discoidea* with increased elevation might be due to its importance for fodder supply. At lower elevations, farmers might have better access to other sources of fodder.

Rankings were not influenced by elevation, despite the relationship between shade tree distribution and elevation. This confirms the findings of Lamond, et al. [15] that farmers' knowledge of tree attributes affecting field interactions between shade tree and coffee is consistent along an elevation gradient.

4.4. Tree Species Ranking in East Africa

Shade tree species in coffee agroforestry systems vary greatly among regions and even within East Africa; hence, it is not possible to generalize findings for the region. Studies with a similar approach to farmers' knowledge of tree species have been carried out in Rwanda [25], Uganda [16,24], and Kenya [15]. Figure 7 combines the tree species included in the rankings and shows the overlaps in the species reported. Only seven shade tree species were commonly recorded in all countries and most of them are exotic. There are also very important tree species that only appear in the ranking of one country, for example *A. schimperiana*, the most important shade tree species for the Mt. Kilimanjaro region.

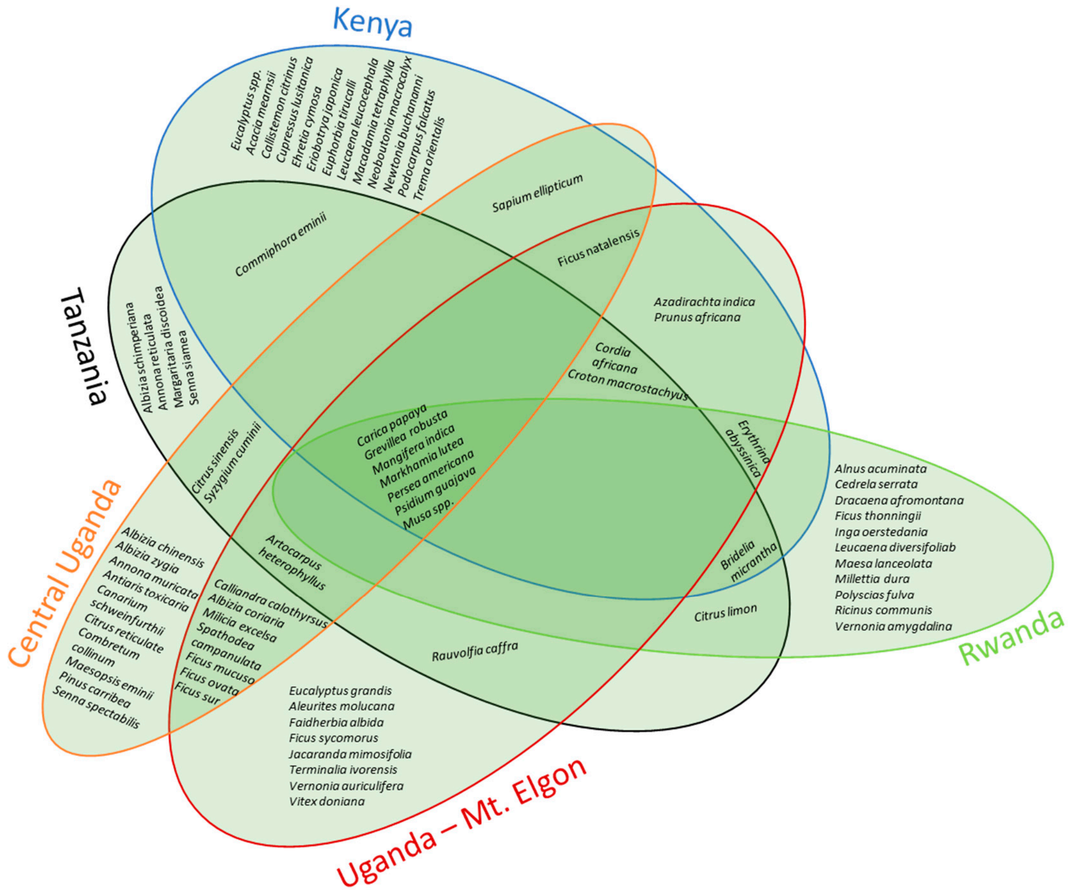

Figure 7. Shade species included in different rankings in East Africa [15,16,24,25].

The comparison of our results with those from similar research done in other East African countries shows the importance of considering the local context in this type of research based on local knowledge. The results linked to specific shade tree species are specific to locations and cannot be generalized. Including an approach based on functional ecology, linking the scores of shade tree species with their attributes can help generalizing results in future studies. This may lead to recommendations of characteristics of tree species that are generally more acceptable. Lamond, et al. [15] already focused more on ranking attributes rather than tree species and Albertin, et al. [47] investigated which tree characteristics are important for coffee farmers. Focusing on tree characteristics might also help to recommend shade tree species that are not very common, but might be a good fit for farmers since ranking is limited to the most common shade tree species, neglecting the importance of rather rare species.

4.5. Resilience of Coffee Agroforestry Systems

Some of the ESs shade tree species can provide, such as temperature regulation or soil moisture enhancement, might help mitigate the impacts of climate change [1,2]. However, not all shade tree species are perceived as similarly effective in providing said services as the scores show (Figure 5). Tree species not influenced by elevation are considered more climate change resilient [16]. This is the case for all investigated shade tree species for our study area within the investigated elevation range, besides *C. africana*, *M. indica*, *S. siamea*, *P. americana*, and *M. discoidea*.

A challenge of the present methodology is the small number of shade tree species that can be included in ES rankings. In order to enhance the ability of the agroforestry system to recover from external pressure and be more resilient in the face of climate change, it is important to protect the biodiversity of the farming systems [48]. It is therefore important to not only recommend the common species mentioned in this paper, but to retain a variety of tree species in the local ecosystem.

A better understanding of the optimal shade intensity and therefore the optimal shade tree density is also essential to tailor advice to farmers. Even though *A. schimperiana* can provide several services, knowledge of the optimal planting density and best management practices in terms of pruning will still be required to achieve optimal shade levels and utilize all potential benefits for coffee production.

For socio-economic resilience, it is important to consult with farmers about their preferences prior to recommending a list of shade tree species, to ensure that the advice fits with their objectives and their constraints. The online decision-support tool for tree selection (shadetreeadvice.org) [23] is a first step in tailoring recommendations for important shade tree species to farmers' preferences. It also needs to be considered that with recurring low coffee prices, focusing primarily on shade tree species that optimize coffee production might not be economically sustainable. The emphasis might shift towards other ESs and shade tree species that increase the economic resilience of coffee farms.

5. Conclusions

This study demonstrated the link between farmers' preference for certain ESs and the planting density of shade tree species that provide these ESs. This shows the importance of understanding the factors underlying farmers' management decisions before recommending shade tree species. Despite being aware of negative crop-tree interactions, farmers might include tree species that are not necessarily beneficial to coffee production in order to acquire other services such as food, fodder, and firewood provisioning, all considered priorities for farmers on the southern slopes of Mt. Kilimanjaro.

Local knowledge of tree species' benefits can be very valuable to local producers; however, it needs to be complemented with expert knowledge to identify biases and fill in knowledge gaps. Even though our study has confirmed that local knowledge of tree species is gender blind, it could still be influenced by other factors such as differences in access to information, access to markets, and/or other socio-economic factors. Contrary to other studies, we did not observe an influence of elevation on the perceptions of tree species' provisioning of ESs. Nevertheless, it will be important to consider environmental aspects in future studies. Another limitation of this methodology is that it only includes the most common shade tree species, leaving aside rare indigenous species with high potential for agroforestry systems. This underestimates the importance of less common species, which might even be superior in providing certain ESs. It may also give the impression that the common tree species alone are enough to support a resilient coffee production system. One approach to improving recommendations might be focusing on the traits shown by highly ranked tree species. This will not only help comparing results from different regions and generalizing recommendations, but also ensure that a wider range of species are included.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/10/11/963/s1, Table S1: Tree species used for the ranking, Table S2: Ecosystem services used for the ranking, Figure S1: Scores and quasi-standard errors of tree species for fodder supply at (a) lower elevations (1148–1335 m asl) and (b) higher elevations (1336–1748 m asl). Red bars show tree species with significantly different scores between the two groups, Figure S2: Scores and quasi-standard errors of tree species for food provision (a,b), shade provision (c,d), and soil fertility (e,f) divided by gender (women are presented in a, c and e; men are presented in b, d and f). Red bars show tree species with significantly different scores between the two groups, Figure S3: Scores and quasi-standard errors of tree species for protection from heat (a,b), and increasing coffee quality (c,d) divided by affiliation to a farmers group (non-members are presented in a and c; members are presented in b and d). Red bars show tree species with significantly different scores between the two groups.

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