

Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in Mount Elgon, Uganda

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Abstract Arabica coffee (*Coffea arabica*) is economically important for many smallholder farmers in the Mount Elgon region of East Uganda, but its production is increasingly threatened by climate change. However, ecosystem services (ES) provided by companion trees in coffee agroforestry systems (AFS) can help farmers adapt to climate change. The objectives of this research were to develop agroforestry species recommendations and tailor these to the farmers' needs and local context, taking into consideration gender. Local knowledge of agroforestry species and ES preferences was collected through farmer interviews and rankings. Using the

Bradley-Terry approach, analysis was done along an altitudinal gradient in order to study different climate change scenarios for coffee suitability. Farmers had different needs in terms of ES and tree species at different altitudes, e.g. at low altitude they need a relatively larger set of ES to sustain their coffee production and livelihood. Local knowledge is found to be gender blind as no differences were observed in the rankings of species and ES by men and women. Ranking species by ES and ranking ES by preference is a useful method to help scientists and extension agents to use local knowledge for the development of recommendations on companion trees in AFS for smallholder farmers.

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Introduction

Coffee is one of the major cash crops for many smallholder farmers in the East African highlands. In Uganda, coffee is the most important export crop with 90% produced by farm households with less than three hectares of land. In fact, Uganda is the second largest coffee producer in Africa, accounting for approximately 2.5% of global coffee production of predominantly Robusta coffee (*Coffea canephora*) (Chiputwa

et al. 2015). Still, Arabica coffee (*C. arabica*) is of significant economic value for Mount Elgon, Uganda's largest Arabica growing region in the East (Van Asten et al. 2011).

The performance of Arabica coffee is strongly influenced by climatic variability, and hence particularly sensitive to climate change (Campbell et al. 2014; Craparo et al. 2015; Davis et al. 2012; Vaast et al. 2005). At temperatures higher than the optimum range for Arabica (18–23 °C), coffee growth is reduced while development and ripening of berry pulp are accelerated, often leading to the loss of beverage quality due to an incomplete bean filling (Davis et al. 2012; Vaast et al. 2006). Drought and high temperatures are the major climatic limitations for Arabica coffee production in East Africa. These climatic conditions are expected to be more frequent with climate change, which already impacted Ugandan coffee sector, and is reducing the area suitable for coffee production (Bunn et al. 2015b; Jaramillo et al. 2011). With coffee-growing altitudes ranging from 1000 masl to over 2000 masl, the Mt. Elgon region can be used as a field laboratory to anticipate climate change and evaluate its impact on coffee, as suitable areas will shift upwards with time (Bunn et al. 2015a, b; Läderach et al. 2011).

In Uganda, the vast majority of coffee is grown in agroforestry systems (AFS) with significant presence of trees and bananas (Van Asten et al. 2012). These systems provide a range of ecosystem services (ES) at plot, farm and landscape levels. The ES can be economical (e.g. timber, fuelwood, fruit, and high value niche markets) or environmental (e.g. biodiversity conservation, carbon sequestration and buffering changes in temperature and precipitation), and can enhance the sustainability and resilience of agricultural systems (Cerdán et al. 2012; Nzeyimana et al. 2013; Perfecto et al. 2007; De Souza et al. 2012). However, the extent to which ES are beneficial for coffee productivity depend on the local environment, livelihood strategies of producers, local market conditions (e.g. coffee prices and local wages), and management practices (e.g. use of external inputs) (Van Asten et al. 2010; Cerdán et al. 2012).

As trees in coffee AFS provide a range of ES that are not directly related to coffee production, they are usually referred to as companion trees and increasingly promoted as a “climate-smart” practice, improving the resilience of coffee production by creating

favourable microclimate conditions, as well as improving soil health (Van Asten et al. 2010; Beer et al. 1998; Campbell et al. 2014; Nzeyimana et al. 2013; Vaast et al. 2006). Trees in AFS increase the biodiversity that enhances biological control of P&D (Staver et al. 2001; Bos et al. 2007; Perfecto et al. 2007; Tschardt et al. 2011). The role of companion trees in climate change adaptation and mitigation needs to be better documented and compared to monocropping systems (Cerdán et al. 2012; Harvey et al. 2014; Rahn et al. 2013; Vaast et al. 2005, 2006). Research on coffee companion trees has been mainly concentrated in Latin America and India, and mostly on their effects on coffee. More research is needed to provide site-specific insights in the benefits and constraints for East Africa as well as to better address the livelihood needs of coffee communities. In this regard, the use of local knowledge on agroforestry can be helpful whilst avoiding expensive and time-consuming trials.

Local tree knowledge plays an important role in traditional agroforestry design, because farmers customise their AFS according to their knowledge and preference of trees and ES that these trees are providing (Cerdán et al. 2012; Valencia et al. 2015). Preferences and management decisions regarding companion trees can be gender-specific, especially with coffee, as it is traditionally a men's cash crop (Kasente et al. 2002; Kelemen et al. 2015; Kiptot et al. 2014; Kiptot 2015). Yet, according to Lecoutere and Jassogne (2016) and Villamor et al. (2014), literature on gender in coffee systems is scarce, and hence there is a need to fill this gap, particularly on local tree knowledge. Local knowledge is, as opposed to indigenous knowledge, not geographically or ethnically specific and can be similar at different locations if within similar agroecological context (Sinclair and Joshi 2000). While Albertin and Nair (2004) and Soto-Pinto et al. (2007) have reported on local knowledge on tree diversity in coffee AFS, it is only in recent years that research has documented on both local knowledge and ES provision in coffee AFS and landscapes (Cerdán et al. 2012; Lamond et al. 2016; Smith-Dumont et al. in press).

The objectives of this research were (1) to develop agroforestry species recommendations along an altitude and climate gradient, using local tree knowledge on ES provision, and (2) to align these

recommendations to farmers' needs by ranking a group of key ES according to farmers' preferences and livelihood strategies. Potential differences between men and women were taken into consideration for both objectives.

Materials and methods

Study area

The research was carried out in the Mt. Elgon region of Eastern Uganda in the districts Bulambuli and Kapchorwa that include the eight sub-counties: Bulegeni, Bumugibole, Lusha, Masira, Simu, Sisiyi, Buginyanya and Kaserem. The area was subdivided into three altitude zones, i.e. the low zone (<1400 masl), the mid zone (1400–1700 masl) and the high zone (>1700 masl). The selected farmers are situated within an area of 210 km² (Fig. 1 (Liebig et al. 2016)).

The mean annual rainfall in the study area ranges from 1200 to 1400 and 1800 mm and the mean annual temperatures are 23, 21 and 18 °C, at respectively low, mid and high altitudes (Hijmans et al. 2005). Although there is a significant local climate variability, Mbogga (2012) suggested that the Mt. Elgon region had experienced an increase in temperatures between 0.4 and 1.2 °C when comparing the 2001–2011 period to the 1961–1990 period. Furthermore, dry seasons are getting longer, causing crop water stress, particularly at lower altitudes (Bunn et al. 2015b; Mbogga 2012).

Due to the relatively high population density of approximately 250 and 300 inhabitants per km² for Bulambuli and Kapchorwa, respectively (Uganda Bureau of Statistics 2016), the landscape is mainly made of smallholder farms (<2 ha) with generally intensive and mixed coffee (*C. arabica*) x banana (*Musa* spp. AAA-EA) based agricultural systems. Coffee is grown under varying levels of shade provided by various companion tree species and banana. Traditional East African Arabica coffee varieties are predominantly grown, including SL 14, SL 28 and Nyasaland (locally known as Bugisu Local). Coffee productivity has been shown to be substantially lower than its potential due to low soil fertility, high P&D pressure and poor land and coffee tree management practices (Wairegi and Van Asten 2010; Wang et al. 2015).

Surveys and data collection

In total, 301 farmers were selected from 196 farms, including 183 men (M) and 118 women (F). Most of the women (105) were from the same households as the men that were interviewed. For the low, mid and high altitude zones there were 103 farmers (63 M, 40 F), 97 farmers (61 M, 36 F) and 101 farmers (59 M, 42 F), respectively. Questionnaires were digitised and used together with plasticised ES pictograms and tree species fact/technical sheets with clear recognizable pictures of the tree shape, mean features of crown, bark, fruits, and leaves.

For each altitude zone, the 20 most abundant species were selected for the ranking exercises, covering more than 98% of the recorded trees. At low and mid altitude, this yielded 23 and 22 species respectively, as the 20th place was shared by several species. At high altitude, only 19 species were recorded and hence all were selected. Since coffee is predominantly intercropped with banana, also providing shade, it was included in the ranking exercise along with tree species. Of those 20 species, the farmers were asked to identify the 10 species they know best for the ranking exercise. The authors considered based on expert knowledge that people can rank to a maximum of 10 items, without losing ranking quality.

Farmers were asked to identify ES that they attribute to companion trees on their coffee plot. Then, considering the time span of interviews and farmer availability, the 12 most mentioned ES were selected and grouped into two categories (Table 1). These were based on the Millennium Ecosystem Assessment classification of Leemans and de Groot (2003), but adapted to the context of this specific study. i.e., the regulating ES were subcategorised into microclimate (buffering temperature extremes and conserving soil moisture), soil fertility (producing mulch and controlling erosion), P&D (decreasing incidence of White Coffee Stem Borer (WCSB) and Coffee Leaf Rust (CLR)), and weed control. The provisioning ES were subcategorised into coffee production (yield improvement/stabilisation and coffee tree life expectancy increase) and tree products (food, timber, and fuelwood). For the latter subcategory, only relevant tree species were analysed (e.g. only food-providing trees for the ES 'food'). The focus on WCSB and CLR is based on the fact that they are the most important P&D problems for the present

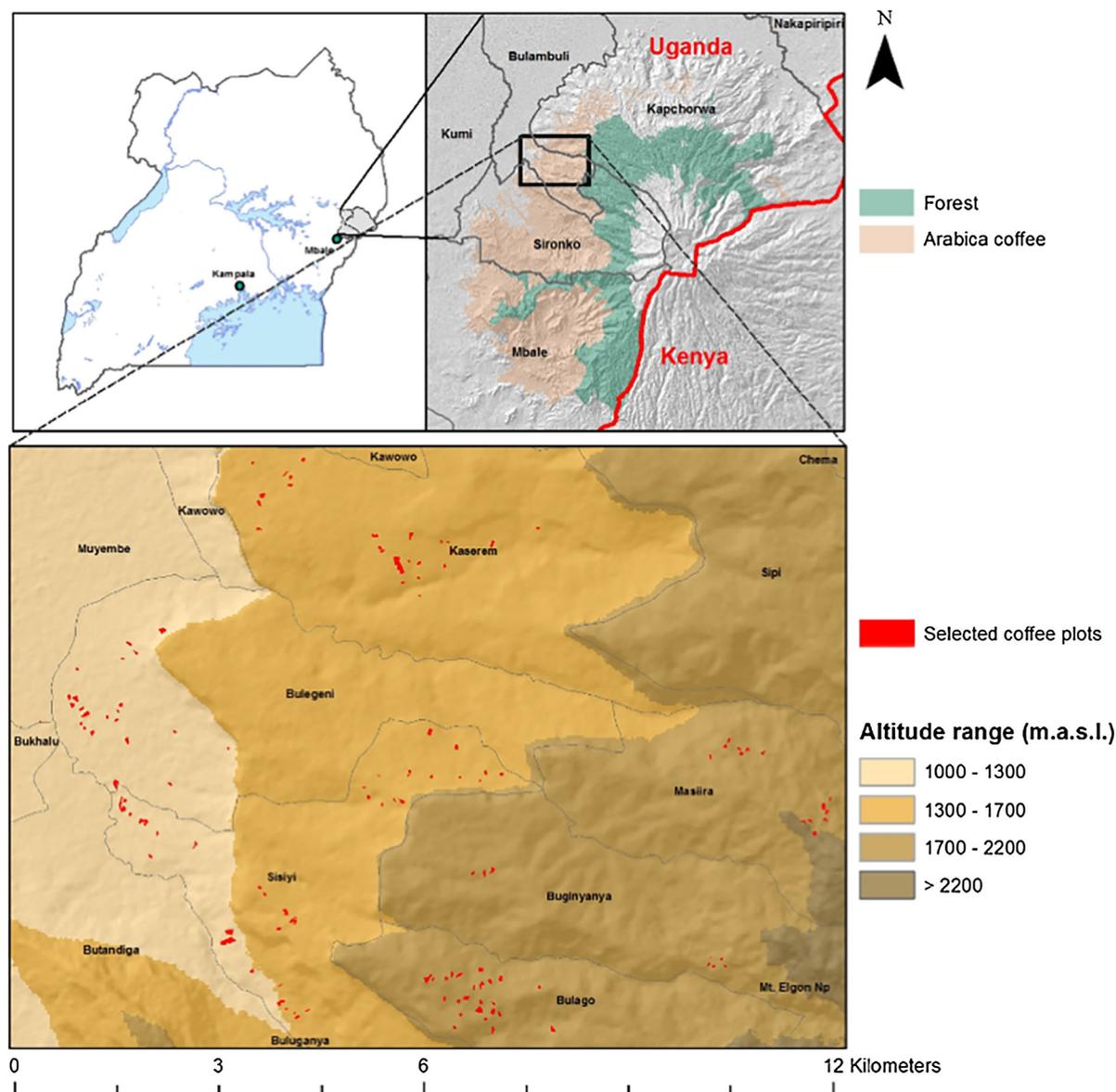


Fig. 1 Location of the study area within Uganda, Mount Elgon area (*top left*), districts of study area (Bulambuli, Kapchorwa) (*top right*), and study site with indication of three altitude zones

(determined by means of cluster analysis) and sample plots (Liebig et al. 2016)

coffee systems over all three altitude zones in Mount Elgon (Liebig et al. 2016).

The questionnaires consisted of three questions: (1) identify 10 tree species that you know best out of the top 20 most abundant species at your specific altitude, (2) rank these species according to each of the 12 ES (tree species with the same rank were allowed, i.e. ties), and (3) rank the 12 ES according to importance for your livelihood.

Ranking tree species and ecosystem services with the Bradley Terry model

A ranking is a relationship between a set of items such that, for any two items, the first is either ‘ranked higher than’, ‘ranked lower than’ or ‘ranked equal to’ the second. Ranking should not be confused with rating, where the items are scored with absolute values on a scale for example from 1 (bad) to 5 (good). In ranking

Table 1 Twelve ecosystem services (ES) attributed to companion trees by farmers are grouped into two MEA categories and six subcategories: microclimate (buffering temperature extremes and conserving soil moisture), soil fertility (producing mulch and controlling erosion), pests and diseases control

| Regulating ES | | | | Provisioning ES | |
|---------------|----------------|--------------------|--------------|-------------------|--------------------|
| Microclimate | Soil fertility | Pests and diseases | Weed control | Coffee production | Tree products |
| Temperature | Mulch | WCSB | Weed | Life expectancy | Food |
| Soil moisture | Erosion | CLR | | Yield | Timber Fuelwood |

(decreasing incidence of White Coffee Stem Borer (WCSB) and Coffee Leaf Rust (CLR)), weed control (weed), coffee production (yield improvement/stabilisation and coffee tree life expectancy increase) and tree products (food, timber, fuelwood)

however, items are scored relative to the other items, hence their scores have no meaning out of the context. Ranking is therefore a subjective evaluation that is useful in pair-wise comparisons.

There are some well-known non-parametric statistical methods based on ranks, i.e. the Kruskal–Wallace test and Friedman test. However, they are not suitable in the context of this study as they do not account for ties in partial rankings (items have the same ranking score). For this reason, the Bradley and Terry (1952) approach was used to analyse the ranking data of tree species and ES. Hence, the data was analysed in R (R Core Team 2015) using the BradleyTerry2 package (Turner and Firth 2012) and three other R functions as explained Van der Wolf et al. (2016).

The Bradley Terry analysis yielded ranking estimates from each individual farmer and used those to create one combined ranking for all the farmers. The analysis also yielded p-values from Wald comparison tests to indicate how significantly different these ranking estimates were from each other. As argued by Van der Wolf et al. (2016), the confidence intervals could vary quite significantly between tree species so they were plotted not solely based on the order of decreasing ranking estimates, but on a combination that includes both the estimate and the size of the confidence interval.

For the sake of developing recommendations and in order to make the interpretation and comparisons of rankings easier and visual, a decision rule was used to group and label tree species based on their ranking estimates. A first group was created starting with the highest ranked species. The next species was included in the group if its ranking was not significantly different from the first species in that group. If there was a significant difference, a new group was created

after which the procedure was repeated. The first two groups were then labelled as ‘high’, groups three and four as ‘medium’, and the remaining groups as ‘low’. All species below the upper four groups were put into a ‘low’ category as their interest as recommended species mainly lies in the upper part of the rankings. Combining groups was necessary to obtain a more or less even spread of differently labelled species, as illustrated in Fig. 2.

Results and discussion

Tree species ranking by ecosystem service and altitude

From the interviews, it appeared that the vast majority of farmers did not have sufficient knowledge on interactions between tree species and WCSB or CLR, respectively ranked by only 22 and 39% of them. Consequently, tree species ranking analysis for those P&D was done with all altitudes combined and could not be presented in Fig. 3 together with the other 10 ES. This analysis showed that only two significantly different groups of ranking estimates were identified for both WCSB and CLR, whereby *Cordia africana*, *A. coriaria*, and *Ficus mucosa* represented the first group (labelled as ‘high’), and all the others species were found in the second group (labelled as ‘medium’). This means that except for these three highest ranked species, there was no consensus in the rankings of the other species for these two locally important P&D and confirms that local knowledge about specific companion tree species and their relationships to coffee P&D dynamics is scarce as explained by Liebig et al. (2016).

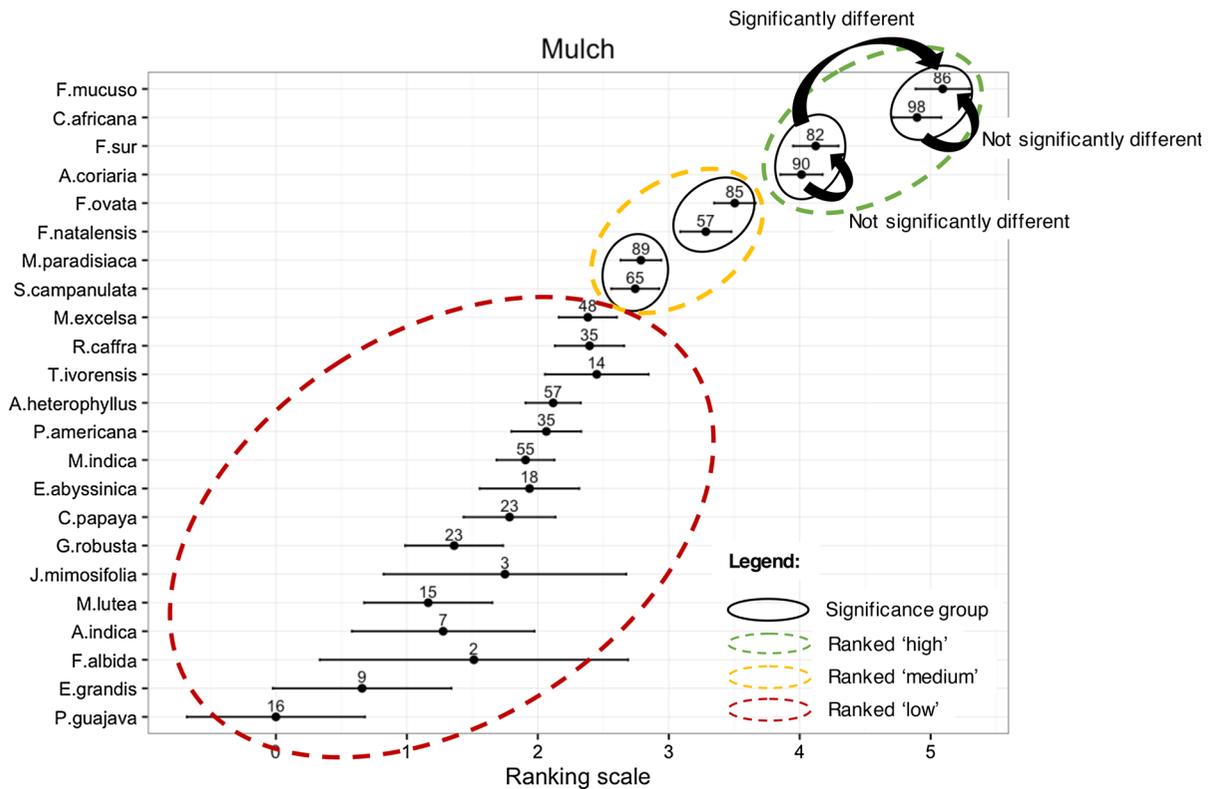


Fig. 2 The ranking result of tree species for the ecosystem service mulch at low altitude as an illustration of how the ranking estimates of tree species were grouped and labelled in order to make the interpretation and comparisons easier and visual. The estimates were annotated with the number of farmers

ranking that species for that specific ecosystem service. The confidence intervals can be seen as an indicator of the frequency and the homogeneity with which farmers have ranked tree species

Cordia africana was exceptionally well ranked for all altitudes and ES (except food) and was followed by the four *Ficus* species and *A. coriaria*. Literature confirms that some of these species are well known for providing several of the presently targeted ES (Meunier et al. 2010; Ndenecho and Lambi 2010; Orwa et al. 2009). *Musa* spp. were ranked from medium to low for all ES other than food, which illustrates that farmers deliberately intercrop coffee and banana very commonly in the very densely populated area of Southern Uganda for food security reasons (Van Asten et al. 2011; Ellis and Bahiigwa 2003). Farmers need to secure food for their households irrespective of any other potential ecosystem service or disservice of banana compared to companion trees.

Overall, different categories of tree species can be identified based on the ranking results. Species such as *C. africana* and *F. mucuso* were ranked high, irrespective of altitude and ES. Likewise, *Spathodea*

campanulata and *Psidium guajava* were predominantly ranked medium and low, respectively. Then there were species whose ranking performance is dependent on altitude or ES. For instance, *Ficus natalensis*, *Ficus ovata* and *Terminalia ivorensis* were generally ranked higher at high altitudes and lower at low altitudes, whereas it was the opposite for *Aleurites molucana* and *Faidherbia albida*. Species that were ranked depending on the ES, were highly ranked only for specific ES. However, their rankings were also dependent on altitude to some extent. For example, *Musa* spp. were consistently ranked high for food, while they were ranked low for the other ES at low altitude. Similarly, *Milicia excelsa* was only ranked high for fuelwood and timber at mid and high altitudes, but ranked low for fuelwood and all other ES at low altitude. Finally, *Eucalyptus grandis* was consistently ranked low for all ES except for fuelwood and timber, but also ranked low for these at low altitude.

Figure 4 shows that the ES rankings at higher altitude are more differentiated as opposed to those at lower altitude with seven, five, and three distinct groups, respectively. In other words, farmers at high altitude were more in agreement to distinguish the ES than the farmers at low altitude.

It was also observed that the relative preference for ES changed with altitude. Whereas at high altitude soil fertility improvement (mulch and erosion) was preferred over microclimate regulation (temperature and soil moisture) and both were preferred over coffee production (yield and life expectancy), the relative importance of the latter two (microclimate and production) increased towards lower altitudes. Hence, all three ecosystem functions were equally preferred at low altitude (Fig. 5). Bunn et al. (2015b) and Läderach et al. (2013) reported that climate change is affecting Arabica coffee most importantly at low altitude, due to higher temperatures, prolonged drought and thus more exposure to water and heat stresses. As such it is hypothesised that low-altitude farmers need a wider set of ES and hence value all ES that help sustain their coffee production by buffering these climate change impacts and increase the resilience of their coffee production.

The provisional services (weed, food, timber, and fuel) were ranked second from last at all altitudes.

Figure 4 shows that within these provisional services rankings, food was preferred over weed at high altitude, and both were preferred over fuelwood and timber for high and mid altitude. For low altitude, these four ES were ranked equally important and relatively better than at high and mid altitudes. At high altitude and far away from markets, households rely much more on their own food production for auto-sufficiency and have less access to markets for timber, fuelwood and fruits compared to low altitude farmers closer to an urban demand. Therefore, it makes sense that food and weed were relatively more important at high altitudes, and that timber and fuelwood increased in relative importance at low altitude.

The consistent and significant low ranking of P&D is attributed to the lack of knowledge, as previously discussed. Still, farmers were able to rank CLR as significantly more important than WCSB at high altitude, probably because incidences of CLR have been found to be higher in unshaded systems which predominate at high altitude (Soto-Pinto et al. 2002).

Lastly, it has to be noted that mulch was the most preferred ES over all altitudes and in particular at high altitude. This preference could be explained by its multi-functionality. Mulch can provide a series of ES, such as soil moisture conservation, erosion control, yield improvement (through organic matter addition

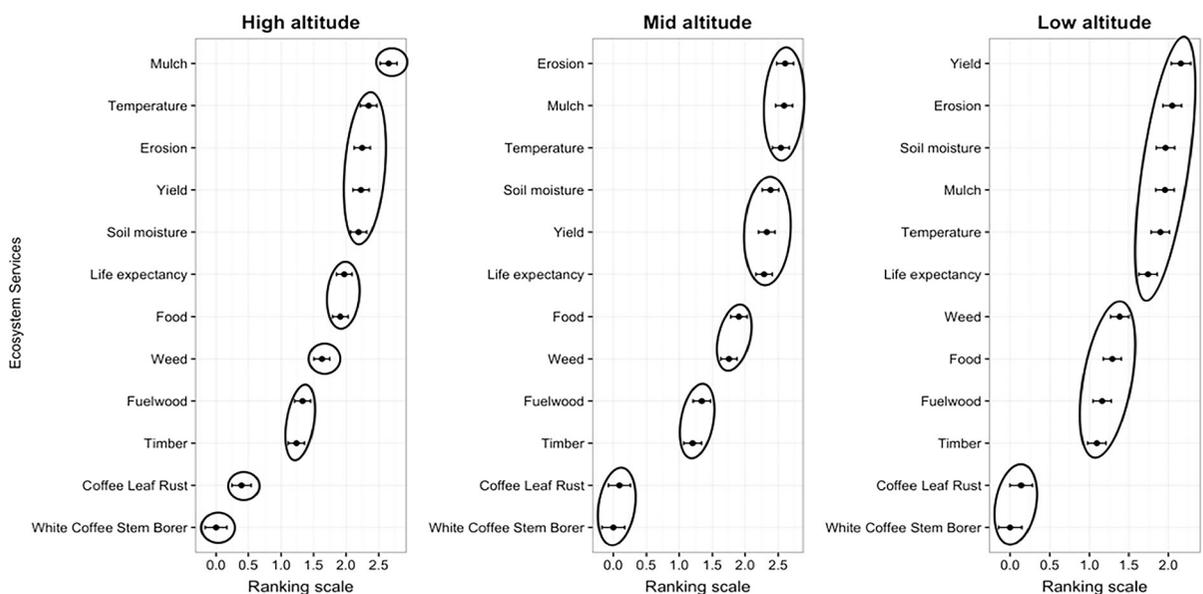


Fig. 4 Ranking of all ecosystem services (including controlling white coffee stem borer and coffee leaf rust) by altitude. Ranking estimates were grouped until the next ranking was significantly different from the first ranking of that group

Fig. 5 The ecosystem services (ES) by altitude and by the subcategories or functions they are represented by. The first group of ES that were ranked highest and whose position was significantly different was labelled as 'high', the second significantly lower ranked group as 'medium' and the rest of the lower ranked ES as 'low'. WCSB and CLR stand for respectively White Coffee Stem Borer and Coffee Leaf Rust

| High | | Altitude zone → | High | Mid | Low |
|---------------|-------------------|-----------------|------|-----|-----|
| Medium | | | | | |
| Low | | ES function ↓ | | | |
| ES category ↓ | ES subcategory ↓ | | | | |
| Regulating | Soil fertility | Mulch | High | Mid | Low |
| | | Erosion | High | Mid | Low |
| | Microclimate | Temp | High | Mid | Low |
| | | Soil moisture | High | Mid | Low |
| Provisioning | Coffee production | Yield | High | Mid | Low |
| | | Life expectancy | High | Mid | Low |
| | Tree products | Food | High | Mid | Low |
| Regulating | Weed control | Weed | High | Mid | Low |
| Provisioning | Tree products | Fuelwood | High | Mid | Low |
| | Tree products | Timber | High | Mid | Low |
| Regulating | Pest and diseases | CLR | High | Mid | Low |
| | | WCSB | High | Mid | Low |

and nutrient cycling) and weed control. At high altitude, compared to low altitude, the need for on-farm trees is lower because people harvest tree products from the nearby forest reserve (Chhetri et al. 2003). Hence, there are fewer trees providing canopy cover and mulching material, which could explain the relative importance of mulch as an ES at high altitude.

Tree species and ecosystem service rankings by gender

From interviews, men were found to be predominantly in charge of coffee management strategies and decision-making on ES and companion trees in coffee plots. However, the rankings between male and female preferences for ES provided by companion trees in the coffee plot at different altitudes did not show any differences (Fig. 6 for all altitudes combined). Still, slight permutations could be observed for erosion, yield, life expectancy and P&D. Likewise for tree species, the rankings at different altitudes were similar between men and women as is illustrated for food and yield in Figs. 7 and 8, for all altitudes combined. This was surprising since they were expected to be potentially gender-specific. Only small and negligible differences were observed (e.g. *Albizia coriaria*).

The absence of gender differences in ES preferences can be explained by the focus of this study on coffee plots and not on the whole farm that generally comprises plots with food crops for which women have more power on management decisions. The absence of gender differences in the tree species rankings, however, is an indication that local knowledge is not only ethnically and geographically blind (Sinclair and Joshi 2000), but also gender blind and therefore adding value to the use of local knowledge in agroforestry research and development.

Limitations of the study approach

The approach used in this study has the advantage that data collection is relatively quick and easy, the farmer's options by context are considered and recommendations can be readily made with the ranking results. However, some limitations have to be considered. First of all, the list of 12 ES is not exhaustive. It was decided to focus on those ES that were relevant to coffee farmers and as such taking into account climate change, food security and livelihood. However, an important ES not presently assessed, is shade quality in terms of light interception over the production cycle particularly. It is recommended to complement the current data base on a wider range of ES in further documentation of farmers' local

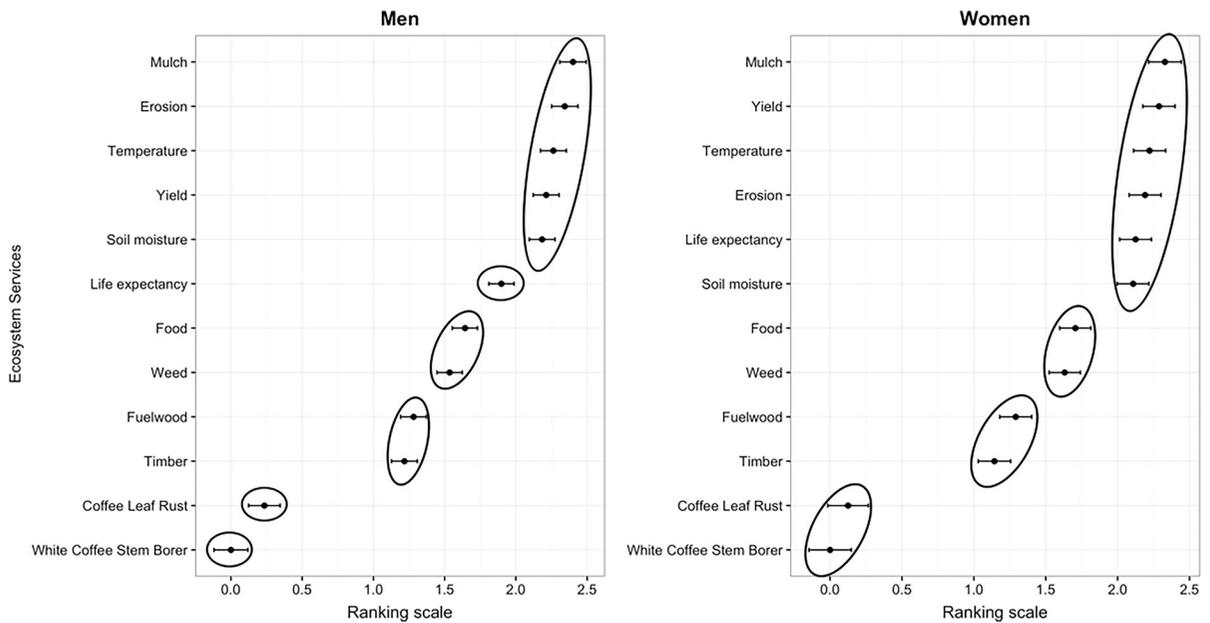


Fig. 6 Ranking of all ES by gender for all altitudes combined. The rankings were grouped until the next estimate was significantly different from the first ranking of that group

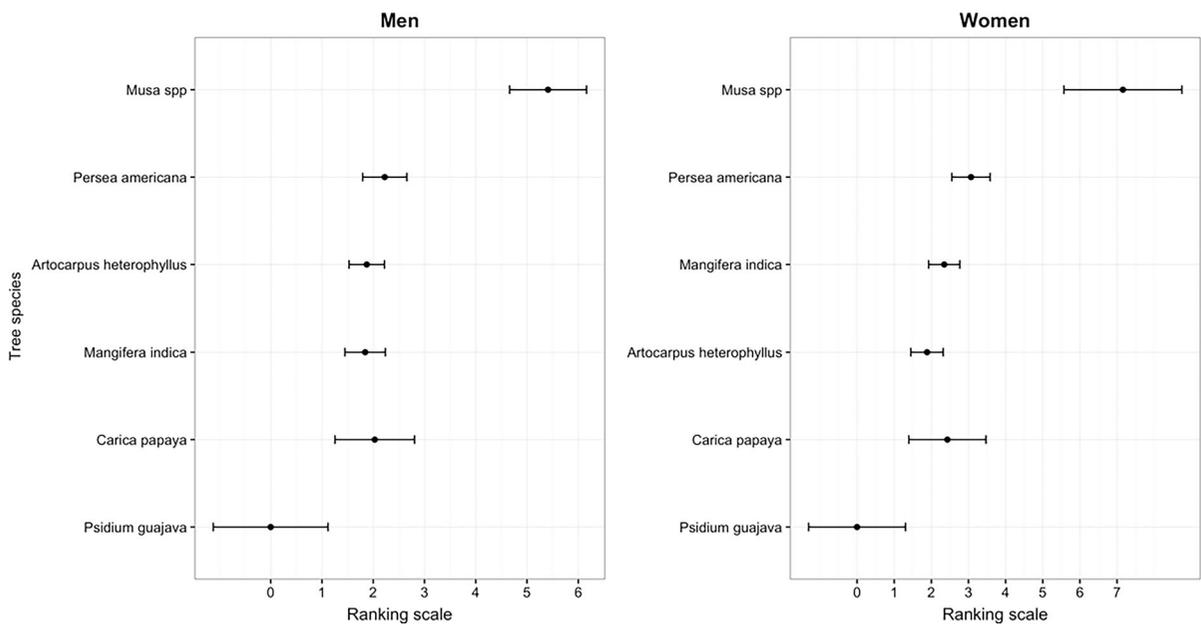


Fig. 7 Rankings of tree species for food provision by men and women separately and for all three altitudes combined

knowledge. Secondly, it has to be emphasised that the ranking results are relative and as such the ranking of individual species should always be considered in relation to the other species concurrently used in the ranking exercise. For instance, a low ranked species is

not necessarily a bad species and could be higher ranked when considered in another context with a different set of species and ES. Thirdly, although local knowledge is site specific and takes into account livelihood for instance, it should be validated and used

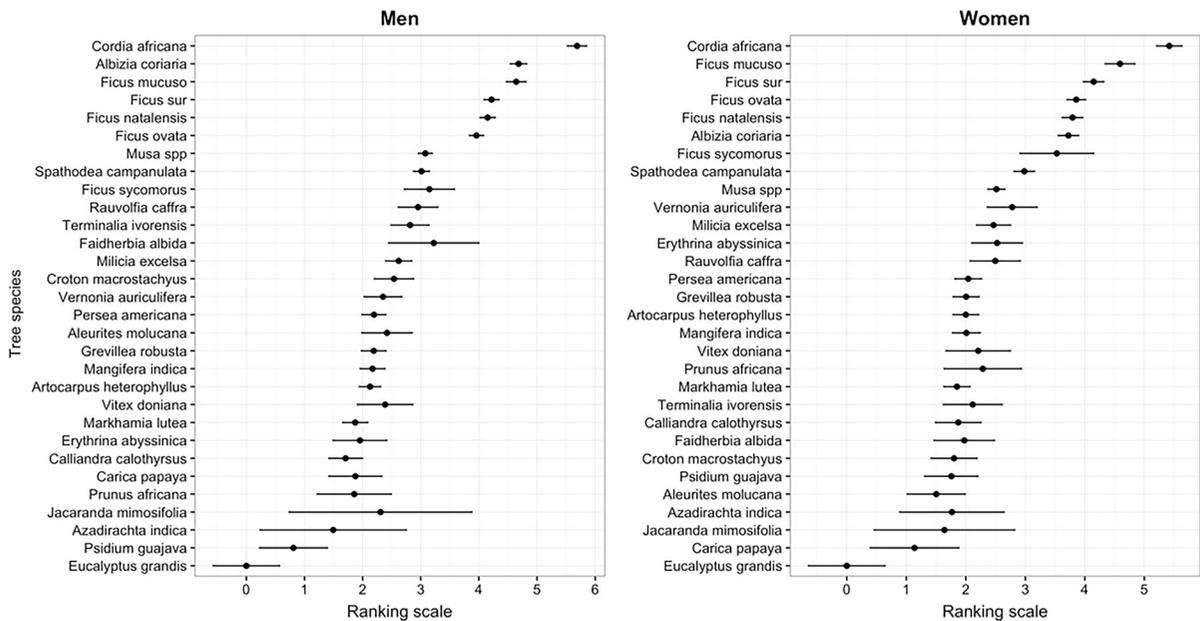


Fig. 8 Rankings of tree species for coffee yield improvement, by men and women separately, and for all three altitudes combined

complementary with expert knowledge of trees and their ES (Lamond et al. 2016; Smith-Dumont et al. in press; Van der Wolf et al. 2016). Furthermore, from a more holistic and realistic farmer’s perspective, final recommendations by agricultural services have to take into account the biophysical and socio-economic contexts, both at farm and landscape level. As such research on local knowledge should also take into account not only the coffee plots, but the whole farm. Lastly, it is possible that the abundance of tree species influences the selection of trees and maybe to some extent their rankings. Locally abundant species are better known than rare ones and might therefore be selected and ranked by more farmers. Consequently, it is possible that unknown and non-abundant but potentially interesting species are ranked with more uncertainty or might even be left out of the analysis.

Conclusion

This paper describes how local knowledge can be used to rank tree species for a range of ES and rank those ES by the farmer’s preference. These rankings can then be used in order to make recommendations for companion trees in coffee agroforestry systems along an altitudinal gradient that are tailored to the farmer’s

needs. Species can be categorised according to their capabilities for climate change adaptation, in terms of their capacity of providing ES under different climates. As farmers are increasingly experiencing difficulties growing Arabica coffee at low altitudes, they need a large set of ES that support their coffee production’s resilience by e.g. contributing to soil fertility, microclimate, and coffee production. Despite the known impact of P&D on coffee productivity and the potential P&D controlling services of companion trees, farmers lacked knowledge on how species affect P&D dynamics. Moreover, it was expected that men and women would rank tree species and ES differently. However, the analysis showed that gender does not influence preferences and management decisions on companion species and the ES they provide, so it can be concluded that local knowledge is gender blind, adding value to its use in agroforestry research and development. A ranking approach has shown to be an appropriate and quick method for scientists to use local knowledge for the development of recommendation tools for coffee farmers and their associations. The ES preference rankings at each altitude are useful to understand the farmer’s needs and their options by context since they inherently include site-specific and livelihood needs. Some limitations to the approach include the non-exhaustive list of ES and the relativity

of the ranking results. The plot-level approach is especially useful if complemented by expert knowledge at farm and landscape level.

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