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Farmer-led approaches to increasing tree diversity in fields and farmed landscapes in Ethiopia

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Abstract Increasing tree cover and managing trees better on farms in Ethiopia supports livelihoods and the environment but most tree-planting schemes promote only a few species. This research aimed to understand farmers' tree planting priorities in Oromia, Ethiopia and address challenges involved in meeting them. Tree species and planting niches were elicited through focus group discussions. Participatory trials compared 17 tree species across seven on-farm planting niches and seedling survival and growth patterns were evaluated. Farmers suggested a high diversity of tree species suitable for each niche with fruit species mainly selected for homesteads. The diversity of desired tree species is much higher than that typically available in nurseries or promoted by tree planting projects. Meeting planting demands was difficult because the existing seedling supply does not support diversity. Evaluation of tree survival showed striking differences among species, farms, agroecologies and planting niches. There was high variation in seedling survival amongst the tree species planted on 1893 farm/planting niche locations, indicating impact of local level risk factors attributable to management, biotic and abiotic causes. Growth differences of the six shared species common to both agroecologies across different niches, showed that the effects of species and niche were significant on growth. A farmer-led approach to increasing tree cover that couples understanding of species and planting niche preferences with appropriate seedling supply and management is proposed as a means to increase the diversity of trees in farmed landscapes.

Keywords Agroecology · Farm · Food security · Homestead · Niche · Priority species

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Introduction

There are multiple reasons for farmers to keep or add trees to agricultural landscapes. Incorporating trees into crop fields and agricultural landscapes may contribute to increased nutrient availability and soil enrichment (Barnes and Fagg 2003; Barrios et al. 2012; Jose 2009) coupled with maintenance of soil organic matter and structure (Akinnifesi et al. 2007;

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Chirwa et al. 2007). In addition, trees in agricultural landscapes can improve water infiltration (Carroll et al. 2004; Ilstedt et al. 2007; Sanou et al. 2010). Farmland trees can also produce fruit, fodder, fuel, fibre and timber that may increase income directly through sales or through system intensification (Nyaga et al. 2015). Increasing tree cover in agricultural landscapes can also enhance carbon storage both above- and below-ground (Makumba et al. 2007; Zomer et al. 2016) associated with production resilience in the face of climate variability (Sinclair et al. 2019). Thus, the use of trees within farming systems can increase food and nutrition security of resource-poor rural people while enhancing the provision of ecosystem services, and helping to create a climate-resilient farming landscape (Barrios et al. 2018; Kuyah et al. 2016; Steenwerth et al. 2014).

Increasing tree diversity as well as tree cover can further enhance food and nutrition security, ecosystem services and products, generating an interest in restoration of biodiversity in agricultural landscapes (Benayas and Bullock 2012). This makes better management of farm-level tree species diversity a key strategy in achieving landscape heterogeneity and biodiversity conservation (Boffa et al. 2005; Weibull et al. 2003). Increased tree species diversity can reduce pest and disease risks related to monoculture and growing only a few tree species across a landscape (Harrison et al. 2019). The use of diverse tree species in agricultural systems can also be viewed as in situ conservation of species and can provide habitat to support other biodiversity (Harvey et al. 2006). Appreciation of the within species diversity that exists amongst populations and the use of seeds or seedlings of appropriate provenances is also very important in ensuring well adapted tree species likely to grow well where they are planted (Derero et al. 2011). Thus, a wide genetic base is desirable for agroforestry tree planting initiatives (Dawson et al. 2009).

In Ethiopia, the important environmental, economic and social roles that trees play across landscapes has been threatened due to deforestation (Duguma et al. 2019) and this, coupled with severe soil loss and intensification of crop and livestock production, has resulted in severe land degradation (Taddese 2001). The depletion of tree resources has also led to shortage of wood and non-wood tree products creating an imbalance between supply and demand (Teketay 2001). Smallholders are opting largely for eucalypt woodlots and boundary planting for wood production (Getahun 2003; Lemenih and Kassa 2014), but these practices do not support biodiversity and other environmental services (Jagger et al. 2005; Kidanu et al. 2005). At the same time, increasing tree cover and diversity in crop fields and on grazing land, could enhance service and production functions (Endale et al. 2017).

Promotion and scaling up of agroforestry, broadly defined as use of trees in farmland (van Noordwijk et al. 2019) is an important strategy in natural resources management in Ethiopia, especially for the highly deforested and degraded highlands (EFAP 1994). Agroforestry is also being promoted in the wind prone lowland areas that comprise a significant portion of the country with highly degraded forest types and rangelands. In Ethiopia, trees are found and valued in multiple niches in farmland including around homesteads, in home gardens, line planting on borders, scattered trees in cropland, coffee farms and parklands, as woodlots and on rangelands (Abebe 2005; De Beenhouwer et al. 2016; Desta and Coppock 2002; Kassa et al. 2010; Poschen 1986; Tsegaye et al. 2010).

The standard practice for scaling up the use of trees on agricultural landscapes in Ethiopia has been to produce tree seedlings of a few species and distribute to farmers and to mount large tree planting campaigns. This approach has weaknesses in that it fails to match the species with farmers specific needs and interests and does not recognise the context specificity of tree preferences and expected performance. Nor does it maintain or increase the diversity of trees in farmlands. An alternative approach involves research 'in' development where scaling-up agroforestry is embedded in development initiatives so that tree planting options are tested across variation in context of farms and agricultural landscapes in a participatory cycle of planning, implementation and evaluation (Coe et al. 2014). The approach includes farmers carrying out simple comparative experiments to find out what works for them. These have sometimes been labelled 'planned comparisons' to distinguish them from the unplanned comparisons from which projects attempt to learn through monitoring and evaluation activities (Coe et al. 2017). Such an innovative approach is expected to result in higher diversity of trees adopted on agricultural lands at the same time as providing information for guiding further interventions (Sinclair and Coe 2019).

The overall objective of the work was to develop and test an approach to discovering the tree diversity that farmers want, to test the performance of some of these tree species across farm niches in both semi-arid and sub-humid agroecologies and thereby to generate knowledge about how to effectively supply species diversity for farm planting. The approach was based on two principles:

1. Farmers understand the diversity of tree species and planting niches in which they will be of value to them.
2. Farmers can test multiple alternatives rather than simply following a fixed recommendation on what to plant, and thereby provide information for themselves, the extension system, policy makers and future planners.

Materials and methods

Site description

The work took place in locations representative of semi-arid and sub-humid zones of Ethiopia. The semi-arid sites are located within the Central Rift Valley, in the East Shewa Zone with average altitude of 1600 m.a.s.l, and receive mean annual rainfall of 750–900 mm and have mean annual temperature of 21 °C (Endale et al. 2017). *Acacia* woodland and savannah being the natural vegetation type, the major crops grown in the area include teff (*Eragrostis tef*) and maize (*Zea mays*) (Endale et al. 2017). The sub-humid sites are in West Shewa and East Wollega zones of Western Oromia, Ethiopia with altitude ranging from 1300 to 2200 m.a.s.l. (Samuel et al. 2019). The mean annual temperature ranges from 14 to 28 °C, and the mean annual rainfall ranges from 1320 to 2000 mm (Samuel et al. 2019). Whereas the natural vegetation is a dry Afromontane and grassland

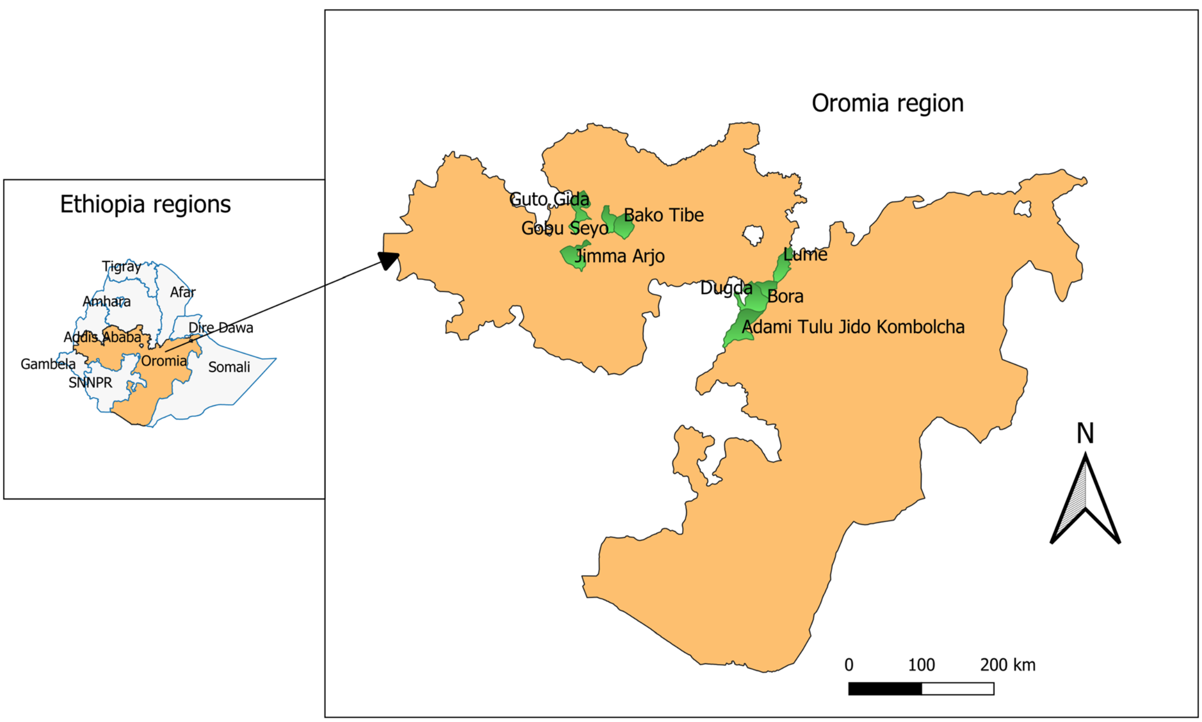


Fig. 1 Location of the project area within Ethiopia and the woredas studied

complex type, the dominant crops grown in the area are maize, sorghum (*Sorghum bicolor*) and teff (Teshome 2014). The semi-arid sites were in four *woreda's* (districts); namely, Adami Tulu Jido Kombolcha, Dugda, Bora and Lume, whereas the sub-humid sites were in four woredas, namely Jimma Arjo Guto Gida, Gobu Sayo and Bako Tibe (Fig. 1).

Farm selection and characterization

Household selection was conducted in a participatory fashion involving local extension workers ("development agents"). After sensitization meetings, farmers willing to plant trees in their homesteads, crop lands and other niches were purposively selected based on perceived convenience to implement the trials and to ensure a range of land holding sizes and other socioeconomic contexts, including varied access to water.

Identification of priority tree species and niches

A total of 24 focus group discussions, three in each site, were conducted to prioritize tree species under different planting niches. A total of 277 farmers (233 male and 44 female) participated as respondents, and a total of 33 extension workers (24 male and 9 female) as facilitators in the focus group discussions. The semi-arid and sub-humid groups were given 50 and 44 tree species, respectively to score and rate their preferred species for planting. The list of the candidate species was prepared based on: (1) former exercises on farmers' priorities, and (2) data from a survey on tree species produced in various nurseries in the eight *woreda's* (Dedefo et al. 2017). Each group was given an assignment of prioritizing tree species for planting under different niches by scoring each species on a scale from 1 to 5. Species were given a score of from 1 (lowest priority) to 5 (highest priority), or zero (not mentioned for that niche).

Tree planting and establishment of participatory trials

Participatory trials were established in four semi-arid and another four sub-humid areas. The steps in the participatory trial process involved (1) setting the research agenda and questions, (2) defining the approach, (3) working out details for implementation, (4) implementing trials, (5) data collection and interpretation and (6) follow up for joint planning of next steps. The tree species considered in the participatory trials included fruit trees and other multipurpose tree species. The participatory trials were established in July–August 2014 under different niches with different tree species. Seedlings were planted under various niches: homestead, crop land, boundary, soil bund, coffee shade and small-scale plantation with individual farmers deciding on species niche matching.

Data collection

Tree seedling survival count was conducted 1 year after establishments of the participatory trials. Height and diameter at breast height (dbh) were collected at the third year after planting. Trees that did not reach a dbh height during the time of data collection were considered as missing data.

Data analysis

Descriptive statistics were computed for tree species and planting niche priorities, seedling survival and tree growth. Counts of the number of groups that mentioned each species for each niche were tabulated ("Appendix"). Species given scores of 4 or 5 by more than 50% of the groups were identified as the highest priorities. When analysing species growth performance for each agroecology and for each niche, those represented by less than three individual trees for a given category were excluded from further analysis. Data on seedling survival was analysed using a binomial general linear model (glm). Growth data (dbh and height) were analysed in a linear mixed model taking agroecology, species and niche as fixed effects, and sites within agroecologies as random effects. Only the six species which were shared between the sub-humid and the semi-arid agroecologies and with at least 10 observations per agroecology or niche, were considered for the growth analysis. When needed, the Tukey HSD mean separation technique was employed for mean separation in cases of statistically significant differences.

Table 1 List of niches (land use categories) and their scores in semi-arid and sub-humid agroecologies

No.	Niches	Mean score out of five	
		Semi-arid	Sub-humid
1	Homestead	5	4.5
2	Soil bund/terrace	2.5	4.8
3	Crop field	2.9	4.4
4	Boundary	3.3	3.5
5	Communal land	2.7	2.2
6	Plantation (woodlot, fodder bank, fruit orchard)	4.3	3.9
7	Coffee shade	NA	3.6

NA not applicable i.e. not included in the semi-arid list as it is not a coffee-growing area

Results

Farmers' preferred tree species and planting niches

From the focus group discussions (FGDs), it was learnt that farmers were interested in planting diverse tree species in diverse niches. During the FGDs, it was documented that farmers consider the following criteria in making tree planting decisions: (1) availability of space and the already available tree stock and its composition; (2) ease of tree protection and care after planting; (3) the challenges that free grazing poses to seedling survival and growth; and (4) potential conflict with neighbours. The scores in the sub-humid agroecology showed that soil bunds, homestead and crop land (intercropping outside of soil bunds) were the three highest priority niches, and in the semi-arid agroecology, homesteads and plantations were given the highest scores (Table 1).

Priority tree species in semi-arid areas

A diverse range of priority tree species were mentioned for different niches. Species that were mentioned often (> 50% of the cases) were many, with the lowest (10 species) recorded for crop lands. Species accorded a high score (4 or 5, 'good') and hence considered particularly suitable for each niche but regardless of the frequency of mention, were also diverse, with crop land again having the lowest diversity with mention of only 30 species. Species rated as 'good' often (> 50% of the cases) were less in number and ranged from 1 for the soil bunds to 19 for homesteads and at least five species for the other niches (Table 2).

Priority tree species in sub-humid areas

A slightly lower diversity of priority tree species were mentioned for different niches in the sub-humid areas than in the semi-arid area. Species that were mentioned often (> 50% of the cases) were many, with the lowest diversity recorded for coffee shade with only 6 species. Across all niches, the number of species mentioned as 'good' (score of 4 or 5) was distinctly lower than the number at the semi-arid site, but there were still many species mentioned. Species rated as 'good' often (> 50% of cases) were few (2 to 4) for all niches except homesteads where 10 species were mentioned. Nine priority species in the homesteads were fruit trees, with the tenth being coffee (Table 3).

The PCA biplot (Fig. 2a, b) showed that in both the semi-arid and the sub-humid sites, the fruit species cluster (circled) were mainly selected for homesteads. Generally, the two agroecologies had distinct priorities (Fig. 3). The six tree species in the top right that had high preference score in both ecozones were *Sesbania sesban, Grevillea robusta, Cordia africana, Leucaena leucacephala, Croton machrostachyus* and *Casuarina equisetifolia*.

Linking priorities to actual planting and survival

Figure 4a, b summarises the status of each species and niche in terms of farmers' priorities, numbers planted and survival rate. A total of 17 different tree species were planted. The actual planting didn't fully reflect priorities as the seedling production and planting mainly depended on the tree seeds that could be availed from nurseries or the fruit tree seedlings that could be procured and availed during planting time. Thus, some lower priority trees were planted, whereas some high priority trees were not (Fig. 4a, b).

Table 2 Farmers' most preferred species for planting under different niches in the semi-arid sites in Oromia, Ethiopia

No.	Boundary	Communal	Crop land	Homestead	Plantation	Soil bund
1	*Faidherbia albida*	*Croton macrostachyus*	*Faidherbia albida*	*Mangifera indica*	*Carica papaya*	*Sesbania sesban*
2	*Euphorbia tirucalli*	*Grevillea robusta*	*Grevillea robusta*	*Coffea arabica*	*Rhamnus prinoides*	
3	*Moringa stenopetala*	*Ehretia cymosa*	*Cordia africana*	*Psidium guajava*	*Mangifera indica*	
4	*Cordia africana*	*Olea europaea subsp. cuspidata*	*Leucaena leucocephala*	*Persia americana*	*Coffea arabica*	
5	*Dovyalis abyssinica*	*Dodonaea viscosa*	*Sesbania sesban*	*Carica papaya*	*Persia americana*	
6	*Dovyalis caffra*	*Acacia tortilis*		*Moringa stenopetala*	*Citrus aurantiifolia*	
7		*Faidherbia albida*		*Cupressus lusitanica*	*Cordia africana*	
8		*Cordia africana*		*Citrus sinensis*	*Musa acuminata*	
9		*Azadirachta indica*		*Rhamnus prinoides*	*Psidium guajava*	
10		*Schinus molle*		*Citrus aurantifolia*	*Citrus sinensis*	
11		*Moringa stenopetala*		*Cordia africana*	*Moringa stenopetala*	
12		*Leucaena leucocephala*		*Ehretia cymosa*	*Vitis vinifera*	
13		*Ziziphus spina-christi*		*Olea europaea subsp. cuspidata*	*Eucalyptus camaldulensis*	
14		*Grewia bicolour*		*Azadirachta indica*	*Prunus persica*	
15		*Eucalyptus camaldulensis*		*Vitis vinifera*	*Casimiroa edulis*	
16				*Musa acuminata*	*Grevillea robusta*	
17				*Grewia bicolour*	*Dovyalis abyssinica*	
18				*Eucalyptus camaldulensis*		
19				*Delonix regia*		

All species frequently (> 50% of cases) identified as good (score 4 or 5) in each niche

Differential survival between species and niches meant that the connection between desired and realised tree diversity was further reduced. The overall mean survival of the seedlings in both agroecologies was 45.6 (± 32.6) at 6 months and 33.6 (± 25.5) % at 14 months. The 6-month survival values of each species are shown in Table 4, and values for the different species ranged from 0 to 100% in different farms/niches.

While farmers express preferences, they are interested in planting a diversity of tree species on their farm—up to 10 species in some cases.

Growth of seedlings at various agroecologies and niches

The mean height of trees in semi-arid areas (n = 733) was 2.8 (± 1.4) m, whereas it was 2.8 (± 1.7) m in the sub-humid sites (n = 2582) ("Appendix"). Growth differences of the shared species between the semi-arid and the sub-humid sites (namely, *C. africana, G. robusta, Jacaranda mimosifolia, Leucaena leucocephala, Moringa stenopetala* and *S. sesban*) under the different niches showed that the effects of species and niche were significant ($p < 0.001$) both on height and dbh. The two major species, *G. robusta* and *S. sesban* attained their highest mean height in the sub-

Table 3 Farmers' most preferred species for planting under different niches in the sub-humid sites in Oromia, Ethiopia

No.	Boundary	Coffee	Communal	Crop land	Homestead	Plantation	Soil bund
1	*Casuarina equsetifolia*	*Acacia abyssinica*	*Eucalyptus camaldulensis*	*Coffea arabica*	*Musa acuminata*	*Grevillea robusta*	*Cajanus cajan*
2	*Grevillea robusta*	*Albizia gummifera*	*Eucalyptus globulus*	*Cordia africana*	*Carica papaya*	*Jacaranda mimosifolia*	*Leucaena leucocephala*
3	*Sesbania sesban*	*Sesbania sesban*	*Grevillea robusta*	*Grevillea robusta*	*Catha edulis*		*Sesbania sesban*
4			*Spathodea nilotica*	*Sesbania sesban*	*Citrus sinensis*		
5					*Coffea arabica*		
6					*Prunus persica*		
7					*Malus domestica*		
8					*Mangifera indica*		
9					*Persea americana*		
10					*Psidium guajava*		

All species frequently (> 50% of cases) identified as good (score 4 or 5) in each niche

humid homesteads and their lowest mean height in the semi-arid boundary plantings (Fig. 5). The highest mean dbh was attained by *M. stenopetala* in sub-humid homesteads, and it also exhibited the greatest variability in size (Fig. 6).

Discussion

Farmers' preferred tree species and planting niches

The prioritization exercise on tree species and planting niches clearly revealed that farmers in Ethiopia have an interest in high species diversity across distinct planting niches consistent with recent findings from Central and West Africa (Dumont et al. 2014, 2019a). It is also clear that the tree diversity desired by farmers is rarely available for planting either in Ethiopia or in other African contexts and often tree planting projects promote only a few species consistent with what is readily available in nurseries (Dumont et al. 2019b). Behaviour change in both projects and nurseries would be required for a diversity of tree species to be promoted for matching to the fine scale ecological differences and farmer circumstances encountered in Ethiopia (Iiyama et al. 2017). If tree planting initiatives fail to respond to the diversity needs of farmers, then (a) they will not be meeting farmers' needs and interests and (b) landscape-level tree species diversity will be much less than it could be. Farmers' interests in planting diverse tree species is due to the different values they attach to and the utilities they obtain from the different tree species, and often farmers associate a species with a primary and a secondary utility (Iiyama et al. 2017). But farmers' preference for planting a given species and the diverse tree species in general is influenced by their perception of planting space availability, existing stock and composition on their land holdings. Interventions to diversify tree seedlings produced in nurseries, which currently deal with only about seven species on average in the *woredas* where the participatory trials were conducted (Dedefo et al. 2017), will be needed to meet farmers' needs. Data from a national survey on tree nurseries (particularly the Oromia region data) (Lillesø and Derero 2019) and that of (Dedefo et al. 2017) together show that some of

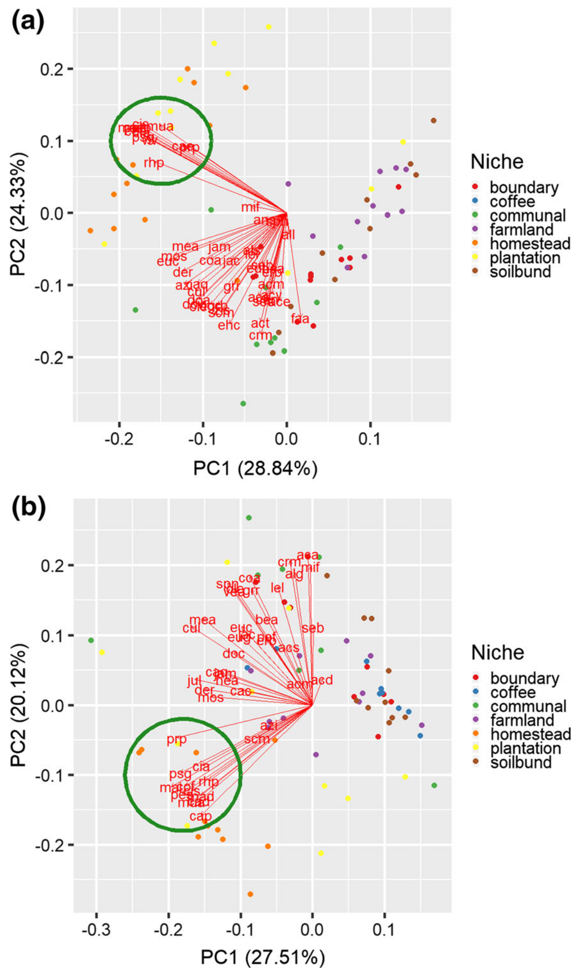


Fig. 2 Principal component analysis biplot of species priority patterns in study woredas of the semi-arid **a** and sub-humid, **b** Oromia. species codes are those in "Appendix"

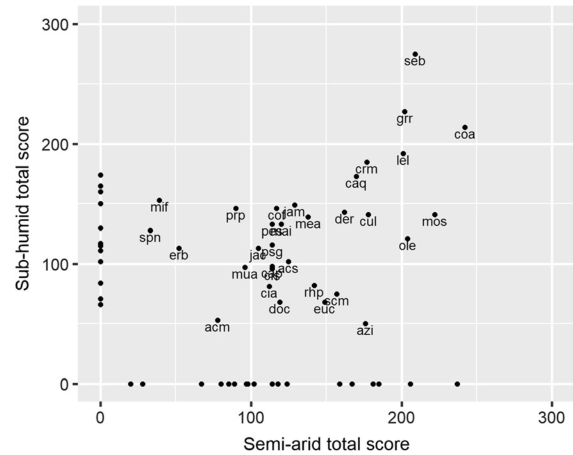
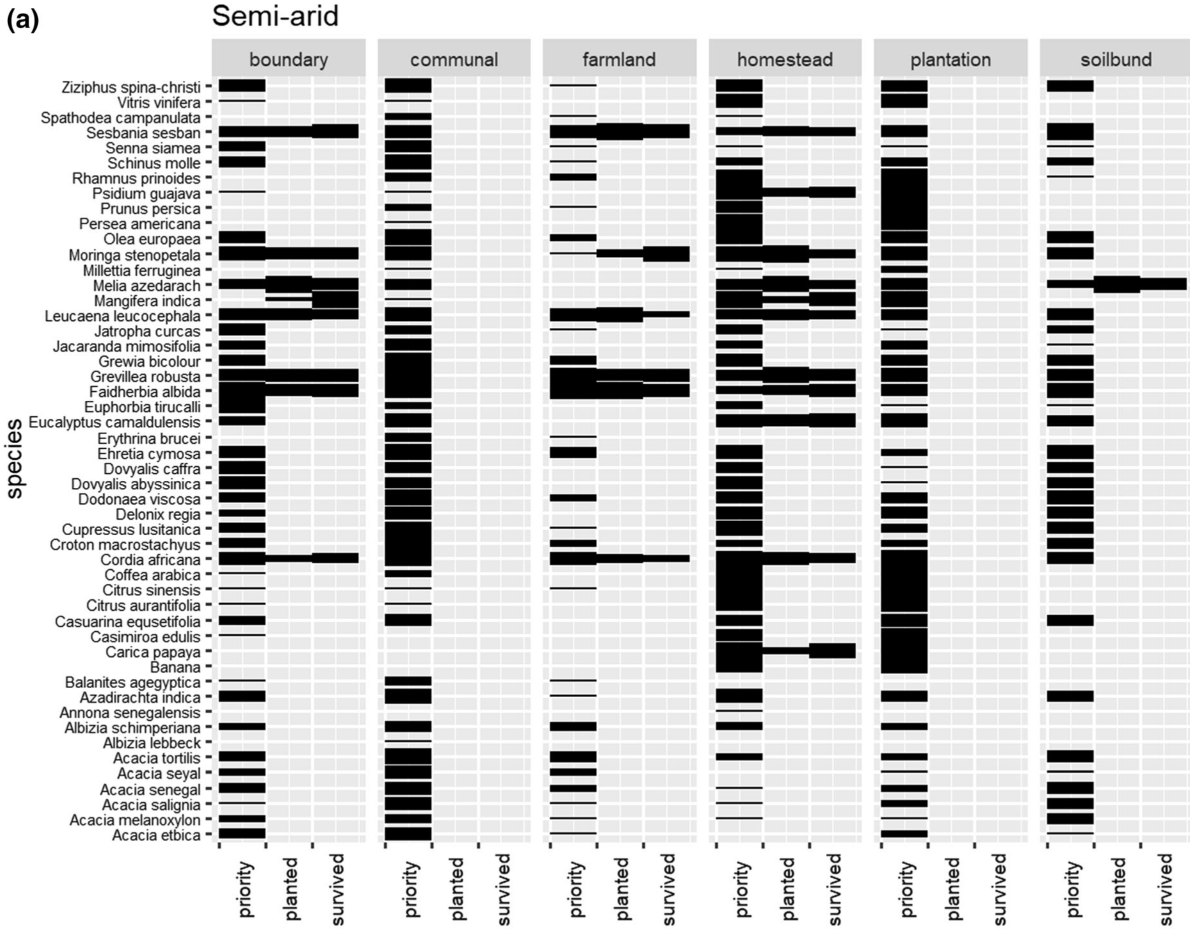


Fig. 3 Scatter plot of the total scores for species priorities in semi-arid and sub-humid woredas of Oromia. species codes are those in "Appendix". Points plotted along

the farmers' priority species were not available in nurseries (e.g. *Ehretia cymosa, Ziziphus* spp., and *Grewia bicolour*) and fruit trees such as *Citrus sinensis* and *Citrus aurantiifolia* were not commonly available to farmers. Generally, there is a shortfall in supply of tree seeds and seedlings of appropriate species to satisfy demand from farmers (Lillesø et al. 2018; Nyoka et al. 2015). Niche preference also relates to ease of protecting and caring for planted seedlings, the challenges that may come from free grazing livestock and the potential conflict that may arise with neighbours, especially in relation to boundary plantings.

The scores in the sub-humid agroecology showed that soil bund, homestead and crop land (outside of soil bunds) were the three highest priority niches with above average scores, and in the semi-arid agroecology, only homestead had the highest rank with above average scores. The results imply that the sub-humid farmers had stronger interest to plant in more niches than the semi-arid farmers. This prioritization helps to decide which tree planting niches to focus on when planning scaling up activities. It can be argued that prioritization of tree species for different tree planting niches is important for niche compatibility in agroforestry and that farmers have good knowledge of matching species with niches (German et al. 2006). More diverse ranges of tree species were mentioned for all niches in the semi-arid areas than in the sub-humid sites probably because the farmers in the semi-arid areas had a stronger desire to integrate more trees in their farmlands. While mean tree density in semi-arid croplands (19 trees ha^{-1}) and grazing lands (115 trees ha^{-1}) that have been reported (Endale et al. 2017) are similar to those (18 and 112 trees ha^{-1}, respectively) reported in sub-humid areas (Samuel et al. 2019) densities in homesteads were much higher in the sub-humid (801 trees ha^{-1}) than the semi-arid (132 trees ha^{-1}) areas.

In both the semi-arid and the sub-humid sites, the fruit species were mainly selected for homestead planting. One addition to homesteads was coffee in the sub-humid zones. This is evidently because farmers attach very high values to fruit trees and coffee and because they could more closely protect and manage these trees in homesteads than elsewhere in their farmlands, consistent with what has been reported



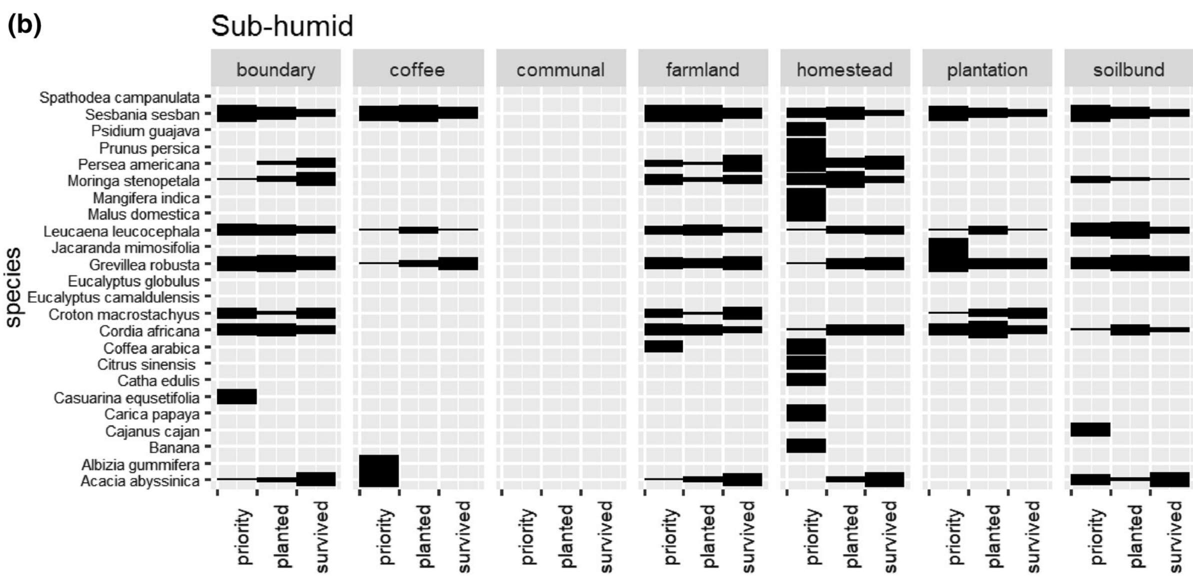


Fig. 4 Species priorities, trees planted and surviving in on-farm niches in semi-arid (**a**) and sub-humid woredas (**b**) of Oromia. Line width is proportional to priority, numbers

Table 4 Survival values of different tree species six months after planting

No.	Tree species	No. of farms/niches	Survival %		
			Range	Mean	Standard deviation
1	*Acacia abyssinica*	71	8–100	65.9	24.8
2	*Albizia schimperiana*	46	0–100	63.0	37.5
3	*Carica papaya*	23	0–100	74.1	28.6
4	*Cordia africana*	197	0–100	30.1	28.0
5	*Croton macrostachyus*	5	13–60	41.3	17.9
6	*Eucalyptus camaldulensis*	38	30–100	72.3	13.9
7	*Faidherbia albida*	102	0–100	53.2	27.9
8	*Grevillea robusta*	311	0–100	57.2	28.4
9	*Leucaena leucocephala*	164	0–100	25.4	27.7
10	*Mangifera indica*	77	0–100	66.9	30.3
11	*Melia azedarach*	150	0–100	40.6	25.8
12	*Millettia feruginea*	129	0–100	38.2	32.3
13	*Moringa stenopetala*	212	0–100	29.0	28.4
14	*Persea americana*	107	0–100	73.6	31.4
15	*Psidium guajava*	43	0–100	40.0	24.1
16	*Sesbania sesban*	194	0–100	35.5	29.5
17	*Dovyalis caffra*	24	50–100	86.1	16.1
	Total	1893	0–100	45.6	32.6

from elsewhere in the Ethiopian highlands (Amede and Taye 2015). Support for farmers to create homegardens where they can grow fruit trees, coffee and vegetables could be expected to improve food security of smallholder farmers. The ecological and socioeconomic sustainability of homegardens such as the traditional enset-coffee homegarden agroforestry systems in Ethiopia has been well documented (Abebe et al. 2010).

The six species that have high overall preference score in both ecozones across several niches were *S. sesban, G. robusta, C. africana, L. leucacephala, C. machrostachyus* and *C. equisetifolia*. *Sesbania sesban* and the *L. leucocephala* are often promoted as fodder species, whereas *G. robusta* and *C. africana* are valued for their timber, *C. machrostachyus* is valued for its role in soil amelioration and *C. equisetifolia* as an ornamental tree, but these species are generally valued for the multiple benefits they provide. Thus, nurseries should produce large volumes of these species as they are likely to be in high demand by many farmers. Other species such as eucalypts may not be suitable for planting in most niches but are planted in high numbers in the form of woodlots. Therefore, detailed planning is needed to decide on quantity of seedling production of different species annually considering the niches and species that farmers want to plant.

Survival and growth of seedlings at various agroecologies and niches

The fact that the overall seedling survival (seedlings that did not die before reaching 1 year old) was about 34% indicating that much remains to be done to improve this. Seedling survival is a function of seedling quality, species-site matching, proper planting at the right time, plant density (Bell et al. 2006), herbivory and disturbance (Bekele 2005; Boerner and Brinkman 1996), edaphic conditions (Reubens et al. 2009), seasonal precipitation patterns (Boerner and Brinkman 1996), watering in dry seasons, and ability to minimize mortality due to insect pests. Results revealed high variability in fruit tree seedling survival in homesteads among farmers, suggesting that farmer-to-farmer exchange of innovative ideas to protect and care for young fruit trees could improve overall performance (Sinclair and Coe 2019). In other niches, farmers preferred timber, fodder and fertilizer trees where the challenge for tree survival is exacerbated when watering is not possible, and cattle freely roam

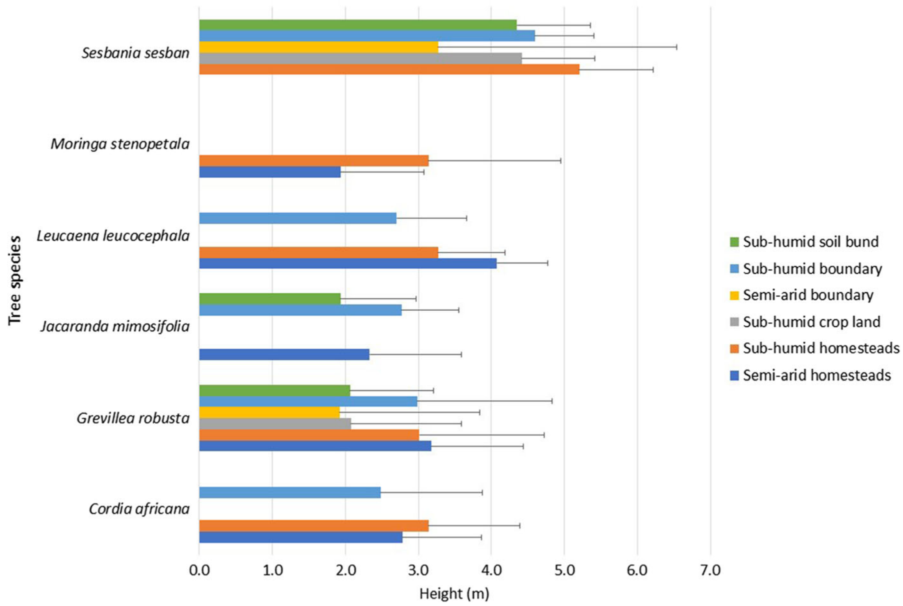


Fig. 5 Mean height attained by the shared species in the sub-humid and semi-arid sites under different niches at the third year after planting

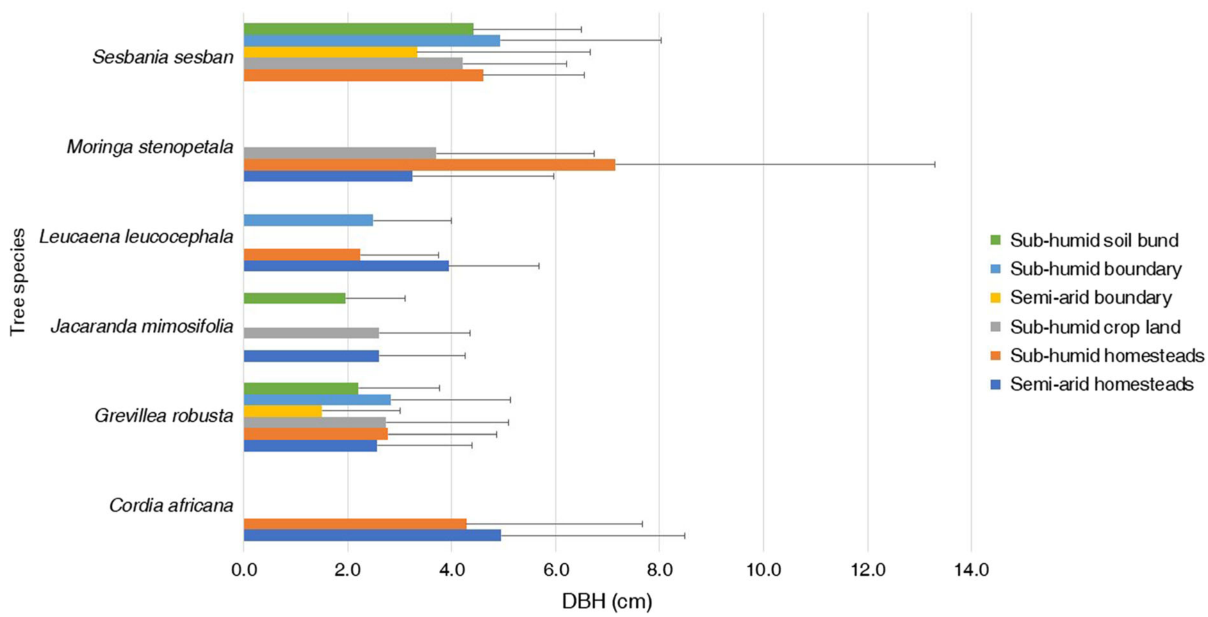


Fig. 6 DBH attained by the shared species in the sub-humid and semi-arid sites under different niches at the third year after planting

and browse the planted seedlings. Options to improve seedling protection through fencing individual seedlings and community bylaws need to be put in place to increase seedling survival in the niches outside homesteads areas. Without such interventions, landscapes will be dominated by a few species that are not susceptible to browsing damage such as eucalypts.

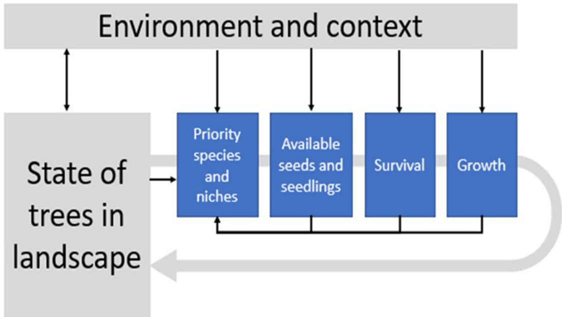


Fig. 7 Conceptual framework for an integrated farmer-led approach to increase tree cover and diversity on farms, showing change in tree cover (grey arrow), filters (blue). (Color figure online)

Seedling survival exhibited large differences between species and niche. This means that species have different responses to the different stresses they face. Despite all the confounding factors, results may be indicative of the most appropriate tree species for the agroecologies under consideration in assuring success of tree planting. Since planting niches have also showed differences in survival, the recommendations have to do with matching species with planting niches or sites. Differential survival between species and niches meant that the connection between desired and realised tree diversity was further reduced beyond the lack of availability of species from nurseries. The variation in survival rate across farms highlights the complexity of tree survival and the potential for learning about it from this sort of trial that involves many farmers. The average survival rates quoted above hide the fact that, for many species, some farmers see survival near 100% while for others most trees die, highlighting the potential for farmer-to-farmer exchange of information to improve performance that can be facilitated by collating and analysing performance data across contexts (Sinclair and Coe 2019) which can be increasingly facilitated through use of mobile phone applications.

Multiple factors contributed to the observed growth differences among the different tree species in various niches: damage by livestock and then sprouting, differences in composting, watering, seedling protection, mixing with other tree species and the like. Growth differences of the shared species between the semi-arid and the sub-humid sites, namely, *C. africana, G. robusta, J. mimosifolia, L. leucocephala, M. stenopetala* and *S. sesban* under the different niches showed that the effects of species and niche were significant both on height and dbh. Similarly, significant differences were reported for growth between agroecologies and niches. For example, significant growth difference was reported for *G. robusta* between niches and for *Eucalyptus* woodlots between agroecologies in Rwanda (Bucagu et al. 2013).

Putting all of the above together, we can see that supporting an increase in tree cover in farm landscapes is more complex than simply planting trees (Holl and Brancalion 2020). A farmer-led approach is required that relates context-specific understanding of farmer species preferences across niches, to availability of seeds and seedlings and appropriate management to ensure their survival and growth (Fig. 7). The grey arrow represents the trajectory of desired tree cover change, based on the general understanding that in much of Ethiopia as elsewhere in Africa, an increase in tree cover and diversity in farm landscapes is needed for both environmental and livelihood reasons. There are filters along the route of tree cover change that modify what is possible. First, farmers priorities must be recognised and understood because they will not plant and manage trees that they do not value. There are then filters of supply of suitable planting material and then what is required for it to survive and grow. These will all be influenced by prevailing policies, the biophysical environment and management. They will also be influenced by farmers' experiences. For example, it is unlikely that farmers will continue to give high priority to growing a species in a niche if their experience suggests it is unlikely to perform well. In terms of this framework, the data we have presented reveals two key points. First, these filters each tend to limit the species and niche diversity resulting from initiatives to increase tree cover. While farmers prioritise many species, this is still a small fraction of possible species for that environment, and a small fraction of those present in natural vegetation. Supplying planting material for preferred species is challenging and will be more so when working at larger scale. Limited survival and growth further reduce the actual diversity of new trees. Secondly, there is variation in what 'passes' each of the filters. This means that there are potential opportunities for increasing the realised diversity of new trees by identifying and replicating good practice from where higher diversity passes through each filter. It is clear that if in some cases it is possible to supply and grow a species, then understanding the factors involved in that success should make it easier to repeat it in future.

Conclusion

This research has shown that there is diversity in the tree species preferred by farmers for planting and in the niches in which they want to plant them. It has also outlined the challenges involved in meeting farmer's tree planting priorities. It was found out that farmers need a high diversity of tree species, that is much higher than that typically available in nurseries. A farmer-led approach to increasing tree cover is proposed to address this that starts with understanding farmers' tree species priorities for different niches and then promoting the tree diversity needed to fulfill this demand as the bedrock of any scaling up activity. Significant differences in tree survival were found among species, farms, agroecologies and niches. The high variation amongst farmers in survival indicates a need to elaborate the impact of local-level risk factors and how they are successfully addressed by some farmers, so that good practice can be identified and shared.

Efforts to increase tree cover in agricultural landscapes should shift from one that simply aims to increase tree numbers, to one aimed at meeting farmer demand for tree diversity. This will require a more nuanced and information-intensive approach. It will also need high investment on each single tree in post planting management to guarantee success and increasing tree diversity. That is more likely to be achieved through an approach of steady, regular and continuous planting and care of a few trees each season rather than large campaigns where farmers plant large numbers of trees at one time.

There are three main strategies of tree seedling production in Ethiopia at present: (1) centralised nurseries run by government or non-governmental organisations (NGOs); (2) cooperatives or group nurseries; and, (3) privately run or farmer nurseries. Some commercial nurseries are specialized in producing fruit trees. A duel approach of encouraging more diversity in seedling production in the existing nursery sector while also organizing and building capacity for farmers to produce and market their own seedlings for species that that they cannot get from existing nurseries is warranted. Consecutive training events could be provided to farmers on topics such as tree planting techniques, protection of seedlings and post planting management derived from good practice identified in participatory trials and fostering farmer-to-farmer knowledge exchange. Where training is accompanied by monitoring, increasingly enabled by mobile phone applications that farmers can use to contribute performance data for consolidated analysis, co-learning about what tree planting practices work where and for whom can be accelerated.

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Appendix

See Table 5.

Table 5 Counts of the number of groups that mentioned each species for each niche and growth of the planted species in the semi-arid and sub-humid agroecologies

No.	Tree and shrub species names	SC	Counts														Growth											
			Semi-arid							Sub-humid							Semi-arid						Sub-humid					
			No. of groups							No. of groups							Height			DBH			Height			DBH		
			HS	CL	BO	SB	CS	PL	CL	HS	CL	BO	SB	CS	PL	CL	X	SD	N	X	SD	N	X	SD	N	X	SD	N
1	*Acacia abyssinica*	aca								1	11	7	8	11	6	8							2.4	1.6	74	3	2.8	57
2	*Acacia etbica*	ace	3	4	11	5		4	9																			
3	*Acacia decurrens*	acd								5	8	7	7	5	4	3												
4	*Acacia melanoxylon*	acm	3	3	5	4		2	5	3	5	4	3	2	3	2												
5	*Acacia saligna*	acs	7	5	8	7		4	8	4	6	4	5	4	4	5												
6	*Acacia senegal*	can	3	5	7	7		2	7																			
7	*Acacia seyal*	acy	3	3	5	5		2	9																			
8	*Acacia tortilis*	act	7	8	9	8		3	10																			
9	*Albizia lebbeck*	all	2	2	1	2		0	1																			
10	*Albizia schimperiana*	als	6	6	5	2		5	7														3	1.4	124	3.3	2	104
11	*Annona senegalensis*	ans	3	2	2	2		2	2																			
12	*Afrocarpus falcatus*	pof								4	7	9	2	2	7	5												
13	*Albizia gummifera*	alg								6	12	9	7	11	6	8												
14	*Azadirachta indica*	azi	12	4	10	5		7	10	6	0	2	0	0	1	3												
15	*Balanites agegyptica*	baa	4	4	7	3		2	6																			
16	*Bersama abyssinica*	bea								3	3	2	3	2	4	7												
17	*Cajanus cajan*	cac								9	9	3	9	1	6	2												
18	*Carica papaya*	cap	12	2	0	0		10	1	12	5	3	1	1	6	1	2.5	0.6	130	9	3.2	127						
19	*Casimiroa edulis*	cae	9	2	2	0		7	1																			
20	*Casuarina equsetifolia*	caq	10	2	12	7		9	9	12	8	11	6	2	9	5												
21	*Catha edulis*	cad								11	4	1	0	0	6	2												
22	*Citrus aurantiifolia*	cia	11	2	2	1		9	2	11	2	1	0	1	7	2												
23	*Citrus sinensis*	cis	11	2	2	0		9	2	12	4	1	1	3	5	1												
24	*Coffea arabica*	cof	11	1	1	0		9	3	12	9	0	1	3	10	4												
25	*Cordia africana*	coa	12	11	12	7		11	10	6	12	10	5	9	10	8	2.8	1.1	39	5	3.5	34	3	1.3	54	4	3.2	52
26	*Croton macrostachyus*	crm	9	11	12	7		4	10	6	11	10	11	8	6	8							2.1	1	38	3	1.6	27

Table 5 continued

No.	Tree and shrub species names	SC	Counts														Growth											
			Semi-arid							Sub-humid							Semi-arid						Sub-humid					
			No. of groups							No. of groups							Height			DBH			Height			DBH		
			HS	CL	BO	SB	CS	PL	CL	HS	CL	BO	SB	CS	PL	CL	X	SD	N	X	SD	N	X	SD	N	X	SD	N
27	*Cupressus lusitanica*	cul	11	6	9	6		6	9	8	3	7	2	3	8	8												
28	*Delonix regia*	der	12	4	9	6		7	8	9	3	5	3	4	6	5	3	0.9	29	2.5	1.2	29						
29	*Dodonaea viscosa*	dov	11	5	10	6		8	9																			
30	*Dovyalis abyssinica*	doa	9	1	10	3		2	5																			
31	*Dovyalis caffra*	doc	9	1	10	3		2	5	6	0	6	0	0	4	6												
32	*Ehretia cymosa*	ehc	10	10	11	8		7	10																			
33	*Erythrina brucei*	erb	3	2	5	4		0	7	6	6	7	7	4	6	3												
34	*Eucalyptus camaldulensis*	euc	7	0	7	4		9	9	0	0	1	1	2	8	8	4.7	2.2	53	3.6	2.5	53						
35	*Eucalyptus globulus*	eug								1	0	1	0	2	9	8												
36	*Euphorbia tirucalli*	eut	4	0	10	2		1	3																			
37	*Faidherbia albida*	faa	5	11	12	9		7	10								2	0.5	7	1.3	0.7	6						
38	*Grevillea robusta*	grr	6	9	9	7		9	10	8	12	11	11	8	11	8	2.9	1.3	146	2.4	1.7	129	2.6	1.7	1624	2.6	2.1	1220
39	*Hegenia abyssinica*	hea								9	6	9	5	3	7	4												
40	*Grewia bicolour*	grb	10	6	11	7		8	10																			
41	*Jacaranda mimosifolia*	jam	7	5	9	4		7	8	11	6	9	7	4	11	5	2.3	1.3	20	2.6	1.7	15	2.5	1.5	107	2.3	1.7	83
42	*Jatropha curcas*	jac	7	3	8	5		2	6	7	4	10	7	4	4	5												
43	*Juniperus procera*	jul								11	3	10	3	0	10	5												
44	*Leucaena leucocephala*	lel	9	9	8	7		10	9	6	12	10	11	8	7	8	4.1	0.7	14	3.9	1.7	14	3	1	71	2.5	1.5	68
45	*Malus domestica*	mad								12	6	1	3	2	8	3												
46	*Mangifera indica*	mai	12	1	1	0		9	3	12	8	2	0	4	7	3	1.4	0.8	19	1.4	0.4	8						
47	*Melia azadirachta*	mea	9	4	8	3		8	8	9	7	10	4	4	7	7	3.3	1.4	125	4.1	3	118	2.4	1.7	9	3.8	1.6	5
48	*Millettia feruginea*	mif	3	2	2	2		3	3	2	10	8	10	9	5	8							1.6	1.2	106	2.7	1.7	48
49	*Moringa stenopetala*	mos	12	6	11	8		10	10	9	10	6	7	2	7	3	1.9	1.1	113	3.2	2.7	70	3.4	1.7	19	6.4	5.1	17
50	*Musa acuminata*	mua	11	2	1	0		9	1	12	4	0	2	2	8	1												
51	*Olea europaea subsp. cuspidata*	ole	10	7	11	7		8	10	4	9	7	6	5	9	8												
52	*Persea americana*	pes	11	1	1	0		9	4	12	7	1	1	6	7	3							1.5	0.9	71	1.7	1	38

Table 5 continued

No.	Tree and shrub species names	SC	Counts														Growth												
			Semi-arid							Sub-humid							Semi-arid						Sub-humid						
			No. of groups							No. of groups							Height			DBH			Height			DBH			
			HS	CL	BO	SB	CS	PL	CL	HS	CL	BO	SB	CS	PL	CL	X	SD	N	X	SD	N	X	SD	N	X	SD	N
53	*Prunus persica*	prp	8	2	1	1		7	4	12	7	3	2	4	8	3												
54	*Psidium guajava*	psg	11	2	2	0		8	4	12	6	1	1	3	7	3	2.2	0.6	9	1.1	0.6	9						
55	*Rhamnus prenoides*	rhp	11	4	2	2		11	4	11	2	2	0	2	7	2												
56	*Schinus molle*	scm	10	5	10	8		7	9	10	3	6	4	1	6	0												
57	*Senna siamea*	ses	5	4	7	4		4	8																			
58	*Sesbania sesban*	seb	10	11	9	9		7	10	10	12	11	12	10	9	8	3.3	0.6	29	3.4	2.1	29	4.8	1.1	285	4.5	2.1	284
59	*Spathodea nilotica*	spn	3	2	2	1		1	2	6	4	8	4	3	6	8												
60	*Vernonia amygdalina*	vea								6	5	10	10	4	6	8												
61	*Vitis vinifera*	viv	11	0	1	0		9	2																			
62	*Ziziphus spina-christi*	zis	9	7	8	7		5	9																			
			Total														2.8	1.7	2582	3	2.3	2003	2.8	1.4	733	4.4	3.5	641

SC species code, *HS* homestead, *CL* crop land, *BO* boundary, *SB* soil bund, *CS* coffee shade, *PL* plantation, *CL* communal land, *SD* standard deviation, *N* number of observations, *X* mean

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