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RESEARCH PAPER

Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits

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Abstract
This study investigates an under-rated and not widely recognized traditional agroforestry practice carried out by smallholders in the highlands of Ethiopia. The purposeful retaining of indigenous trees on farmers' croplands is recognized as separate from other agroforestry practices. Farmers cultivate indigenous trees for a variety of benefits, including livelihoods, ecosystem services and the existence of scenic and economically valued birds. The adoption of farmland agroforestry has been driven by similar household-level variables that explain the adoption of many other agroforestry practices. However, in contrast to other agroforestry practices farmland agroforestry is not a management priority for farmers, an observation that appears due to a lack of appreciation of naturally occurring trees. Because agroforestry on farmland is declining, interventions are required that improve extension services, availability of indigenous tree seedlings and credit, support reliable legal frameworks and land titles, and foster the processing and value adding of tree products suitable for higher value uses.

Keywords Farmland agroforestry · Indigenous knowledge · Landholder livelihoods · Trees on farms

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Introduction

Agroforestry is a land use system that deliberately integrates trees or shrubs with agricultural crops and livestock in the same land management system (Nair 1993). Agroforestry can contribute to sustain agricultural production (Roshetko and Bertomeu 2015), improve food security (Mbow et al. 2014), help alleviate temporal shortages of water and energy (Coe et al. 2014), and facilitates adaptation to climate change (Vignola et al. 2015).

Depending on the configuration of the agroforestry land use, various types of agrosilvicultural, silvipastoral and agrosilvipastoral systems can be distinguished (Nair 1985). The practice of purposefully retaining trees on cropland has been described as a traditional agrosilvicultural practice common throughout the tropics (Nair 1991). Most often, this practice involves various indigenous, typically multipurpose tree species that are left by farmers to grow in a dispersed irregular pattern on their cropland. While indigenous trees are also commonly retained by farmers around their homesteads for a variety of benefits, the focus of this paper is on trees retained on farmland, i.e. fields typically used for cereal or other cropping. The term '*farmland agroforestry'* is used in here to refer to this practice.

Despite its apparent ubiquity, farmland agroforestry has been poorly defined in the scientific literature. Existing classification schemes distinguish agroforestry practices primarily by the spatial arrangement of trees (Sinclair 1999), or by the predominant features of the tree components (Schoene et al. 2007). The systems environmental adaptability or socio-economic performance and management intensity serve as further dimensions to classify such systems (Nair 1993). However, these classification schemes only weakly discriminate between the deliberate retaining of naturally occurring trees on cropland and other practices of tree growing on farms, such as planting of eucalyptus trees on plot contours as a woodlot or the retaining of naturally regenerated *Croton macrostachyus* around homesteads. In the absence of a clear definition, various terms have been used in the scientific literature to refer to this practice, such as 'multipurpose trees on farms' (Nair 1991), 'farmer-managed natural regeneration' (Haglund et al. 2011), 'agroforestry parkland systems' (Bayala et al. 2011) and 'silvoarable agroforestry' (Graves et al. 2017) to name but few.

The conceptual ambiguity can potentially affect accurate assessment of these systems. Given that the environmental effects, economic costs and benefits as well as the socio-cultural implications of the various agroforestry practices are determined by their particular characteristics and hence may differ between the locations, a more precise differentiation and detailed understanding of these practices is needed (Tolunay et al. 2007).

In Ethiopia, smallholders practice various agroforestry practices depending on the socioeconomic and biophysical conditions which has livelihood implications (Abiyu et al. 2016). The deliberate retaining of naturally occurring trees on farmlands is a common land use practice carried out by these smallholders for monetary, material, environmental, and cultural uses (Jamala et al. 2013; Iiyama et al. 2017). However, the practice of farmland agroforestry is declining in many agricultural landscapes in Ethiopia due to increase in fuelwood demand and degradation of nearby forests

(Onyekwelu et al. 2015), agricultural intensification, the increasing popularity of exotic tree species which generate larger economic benefits for farmers (Teshome 2009), and the fact that land proclamations do not specify clear instructions for farmers on how to manage and conserve indigenous trees.[1]

This study was conducted in the Dera *Woreda*[2] in the Amhara region of northwestern Ethiopia to: (a) characterize the existing farmland agroforestry systems practiced by smallholder farmers; (b) investigate the type of benefits derived from these practices; and (c) identify the factors that affect farmers' decisions to practice farmland agroforestry. Thus, this paper contributes to the literature by exploring and describing in detail the practice, socio-economic determinants and perceived benefits of farmland agroforestry, aspects that the current literature has insufficiently addressed so far as described above.

A systematic review[3] of the recent agroforestry literature revealed that the purposeful retention of naturally occurring trees on farmlands has rarely been rigorously and comprehensively investigated. Using the search terms 'agroforestry', 'farmland', 'parkland', 'livelihoods', 'adoption', and 'trees on crop lands', as well as meaningful combinations of these keywords, a total of 1241 studies were identified that appeared since year 2000 in the Web of Science. Articles which (a) presented original research, (b) made mention of the purposeful retention of trees on farmlands, and (c) reported both socioeconomic and biophysical analyses were selected by careful assessment of the titles, abstracts, keywords and where necessary further sections of these publications. Applying these criteria reduced the total number to 21 publications (Table S1, Supplementary files).

The review revealed the shortage of studies that specifically address the practice of farmland agroforestry. This seems closely related to the lack of conceptual clarity and rigor to distinguish farmland agroforestry from other agroforestry practices. Many of the studies that investigate farmland agroforestry do so implicitly and fail to recognize this as a separate practice (e.g., Abiyu et al. 2016; Etshekape et al. 2018). Results reported by these studies can hence not completely illuminate this practice and the factors that determine its socio-economic and environmental characteristics. Most of the studies that explicitly discriminate farmland agroforestry from other

[1] According to Article 10(1) of the FDRE Federal Nagarit Gazeta Proclamation no. 425/2005, land entitlement will be withdrawn if land is damaged. According to Article 13(1) land use plans shall be prepared by the competent authority based on the watershed approach. According to Article 13(2) of the revised Amhara National Regional State Rural Land Administration And Use Proclamation Zikir HIG Proclamation no.133/2006, rural land use plans shall be prepared considering land use, soil type, air condition, vegetation coverage and socio-economic situations based on a catchment approach; and according to Article 20(1) land users shall plant and properly protect trees around their land. However, the common practice of replacing indigenous trees on farms by fast-growing exotic tree species is accepted as complying with these regulations.

[2] In Ethiopia government administration is at a federal or national level, then regional, zonal, *Woreda* and *Kebele* levels.

[3] This article contains supplementary materials available on the Springer website, including a table on systematic review of literature, a figure for livelihood ranking, table for Tropical Livestock Unit (TLU) in which each livestock species, gender and age category is measured by a standard livestock unit conversion factor as well as table for variables explanation.

forms of agroforestry are limited to the analysis of aspects determining adoption and socio-economic benefits (e.g., Weston et al. 2015), and largely fail to address the wider integration of this practice in the tree-based household livelihoods, its trends of adoption as well as drivers of species diversity.

Further investigations are needed addressing the synergies and tradeoffs as well as causal links associated with managing and utilizing naturally occurring trees in agricultural landscapes (Kuyah et al. 2016). Studies that quantify local extinction and value ascribed to retained species can help to acknowledge the contribution of this agroforestry practice in agricultural landscapes (Kuussaari et al. 2009; Luc and Lionel 2018). Thus, this paper illuminates knowledge on farmland agroforestry by specifically studying the practice and its integration with smallholder livelihoods.

The Study Area

The study was conducted in Dera *Woreda* (11°10′00″–11°55′00″N and 37°25′00″–37°52′05’’E), located in the South Gondar administrative zone, Amhara Regional State of Ethiopia (Fig. 1). The *Woreda* covers a land area of approximately 1.5 million ha, of which about 85% is classified as *Woina-dega* (i.e. elevation ranges from 1500 to 2300 m), and 15% is classified as *Dega* (2300 to 3200 m) agro-climatic zone, respectively. The topography comprises uneven and ragged mountainous highlands, extensive plains and deep gorges (Amare et al. 2017a, b).

The rainfall is characterized as having a bimodal distribution with the major rainy season occurring between June and August (locally called *Kremit*) and a short rainy season from March to May (*Belg*). The annual average rainfall varies between 1000 and 1500 mm, while the average monthly temperature ranges from 13 to 27 °C (*Woreda* Bureau of Agriculture 2014). The ecological conditions in the study area are relatively homogeneous without much microsite variation. The forest, shrub (bush) and outcrop lands constitute 8.8, 10.3 and 8.8% of the total land area of the *Woreda*, respectively. Almost 46% of the *Woreda* area is agricultural land, and agroforestry has been practiced traditionally on most of this land. Overall, the study area is typical of Ethiopia’s mid-elevation highlands where mixed farming systems predominate and a combination of agricultural crop and livestock production for subsistence and market production are the major livelihood activities of farmers. The official population of the *Woreda* is approximately 260,000 (*Woreda* Bureau of Agriculture 2014) Click here to enter text., with a national annual average growth rate of 2.74% between 2000 and 2016 (UN 2018).

Dera *Woreda* was selected purposively due to (a) environmental conditions representative of Ethiopia’s middle-elevation highlands that facilitate a wide range of agricultural practices, including agroforestry; (b) the traditional occurrence of farmland agroforestry practices in this area; and (c) the increasing incidence of land degradation and tree clearance as a consequence of a growing population pressure and other forces. As farm-households represented the main economic and income-pooling unit in the study area, it was chosen as the unit of analysis for this study.

Table 1 Population and sample size

Kebele	Population in households		Sample size	
	Male-headed HHs	Female-headed HHs	Male-headed HHs	Female-headed HHs
Mirafit	1001	139	56	8
Mitsili	2359	330	132	19
Korata	1637	228	93	13
Wonchet	949	69	53	4
Total	5946	766	334	44

HHs households

Research Method

A sample of households in Dera Woreda was selected using multistage sampling. First, from 29 rural *Kebele*s (the lowest form of administrative unit in Ethiopia) in the *Woreda*, four Kebeles were selected purposively for the study due to the existence of agroforestry practice dominated by indigenous trees. Simple random sampling was used to select respondents from the four *Kebele*s. A total of 378 households, corresponding to 5.6% of the total population of the *Kebeles*, was selected for the household survey (Table 1) according to Yamane (1967) at a 95% confidence level and $p = 0.05$.

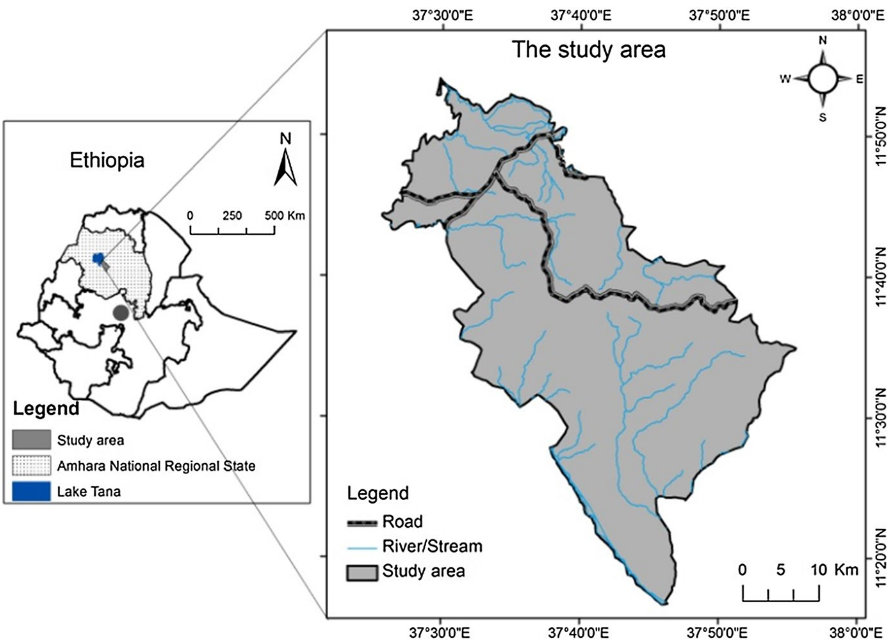

Fig. 1 Location of the study area

These interviews were conducted with the main decision-maker of the household. Gender of household head served to represent socio-economic differences between households, such as labor force size (total family size for male headed households is 6.04 while for female headed is 3.98 and the active labor for female headed households is 2.4 and for male is 3.1) and resource access. In addition, four focus group discussions (FGDs), with 8–28 participants, and transect walks were conducted to validate information gathered from household survey.

Data were collected in 2014 using household survey and checklists of questions for focus group discussions. The survey questionnaire was designed to collect data on: (a) local community perceptions about the degradation of natural resources; (b) the practices of farmland agroforestry by each farm household; and (c) household preferences for various indigenous tree species for specific benefits. The questionnaire was organized by first asking open and closed questions about the agroforestry practices followed by dichotomous choice questions of 'yes' or 'no' for the presence of the particular indigenous tree species, among those listed in the area, on the respondents' farmlands.

Due to research time and budget constraints, no physical inventory of the number of indigenous trees on the respondents' farmlands was conducted. Aerial imagery from Google Earth was used to obtain data on tree density by setting 2010 and 2015 on the timeline (for dry seasons) on a sample of the research area to estimate the change of tree density on farmlands located on the main farming block (i.e. considered as the local major crop production area). According to information obtained from observation during transect walks and aerial imagery, the main farming blocks in the sample area was located at a distance of between 20 and 60 meters from residences. Areas within this distance were considered as homesteads and were excluded from the analysis. Arc Map 10.1 was used to analyze the spatial extent of farmland agroforestry. Farm plots were counted after categorizing them into farm parcels with and any without trees, irrespective of the parcel size.

Survey data were analyzed using descriptive statistics and econometric methods. Pearson Chi square and paired sample t-tests were used to test categorical and continuous independent variables and test the dependent variables for statistical significance of differences. The dependent variables were measured at the household level as dichotomous responses, separating 'adopters' from 'non-adopters' of farmland agroforestry, as well as the absolute number of indigenous tree species retained by the respondents on their farms. Such classification enables comparison of groups in a pseudo-experimental design which is an approach adopted in other studies (e.g., Amare et al. 2016). Land area was considered an appropriate proxy for the environmental and biodiversity-related benefits of farmland agroforestry due to the homogenously distributed land area among households and uniformity of environmental conditions (Table 2). The dichotomous response logit econometric model (used for example by Gyau et al. 2015) was employed for analyzing determinants of practicing farmland agroforestry. The negative binomial regression model (UCLA 2017) was used to investigate the factors affecting the number of indigenous tree species retained by farm households.

Results

Socioeconomic Characteristics of the Respondents

The number of farmers who practiced farmland agroforestry was considerably greater than the number of non-adopters. As revealed by t-tests, there were significant differences between adopters and non-adopters of farmland agroforestry with regard to means for respondent's age, family size, active labor force, total land area, land area on the main farming block, number of tropical livestock units (TLU), and average amount of credit used over the five year period. The Chi square test further identified significant differences in the scenic value placed on birds, access to credit, adoption of irrigation, practice of apiculture and adoption of agricultural technologies among adopters and non-adopters of farmland agroforestry (Table 2).

Adopters of farmland agroforestry were found to have a significantly higher average age, larger family and active labor force compared to non-adopters. Further, they owned significantly more land in total, had larger plots on the main farming block, and held more livestock. Also, adopters of farmland agroforestry systems were significantly more likely to access credit, value birds for their scenic value, and practice irrigation and apiculture. Adopters had generally accessed significantly larger amount of credit and a higher number of them had adopted agricultural technologies compared to the non-adopters. There was no statistically significant difference between adopters and non-adopters with regard to access to extension service (Table 2).

Tree Product-based Livelihoods

The income from tree products originating from farmland agroforestry as well as from exotic tree species contributed 7% of the average total annual income (ETB 10,300) of the households of Dera *Woreda*. There was no statistically significant difference in the average total annual income between adopters and non-adopters ($t=-1.16$, $p=0.87$; Table 2). Compared to other farm activities, tree products were ranked less important for subsistence in household economies (ranked 5th behind food crops, livestock, cash crops and fruits) and only 7.7% of the farmers ranked tree products as their most or second-most important livelihood source (Figure SFigure S1, supplementary file). Seasonal employment making tree products from farmland agroforestry was reported by 10.3% of respondents. Their activities included local farm implement making (4.0%), lumber extraction (3.7%) and local furniture making (3.2%), and generated an annual income of ETB 397.18 (±117.67) on average. However, traditional processing technologies prevailed, characterized by use of mainly manual tools (e.g. handsaw) and production of low-value products for subsistence and for local sale. While approximately two thirds of these households did not face significant limitations, resource shortage (especially of *Cordia Africana*, 31.5% of responses) was identified as a major limitation by some of the farmers that engaged in the production of sawn timber products.

Farmland agroforestry served as the most important source of fuelwood for 13.1% of respondents. The remaining households mainly obtained their fuelwood from

Table 2 Characteristics of adopters and non-adopters of farmland agroforestry

Variable$^{\pi}$	Adopters (n = 283)	Non-adopters (n = 95)
Age (years)	43.45 (± 0.68)*	41.57 (± 1.28)
Years of schooling (years)	0.86 (± 0.12)	0.76 (± 0.21)
Family size (No.)	6.05 (± 0.12)***	5.05 (± 0.24)
Active labor force (No. aged 15–64 years)	3.15 (± 0.085)**	2.53 (± 0.14)
Land area (ha)	1.20 (± 0.04)	0.97 (± 0.07)
Area of the main farming block (ha)	0.73 (± 0.03)**	0.59 (± 0.06)
TLU (tropical livestock unit, no.)	5.16 (± 0.19)***	4.27 (± 0.34)
Income from tree products (ETB)[a]	1573.51 (± 258.45)	1109.36 (± 649.84)
Total income (ETB)	10,716.87 (± 781.33)	8926.10 (± 1297.21)
Farmers who have accessed credit (%)	47.88***	10.32
Average amount of credit (ETB)	2937.26 (± 252.43)***	1552.21 (± 210.85)
Average irrigation area (ha)	0.14 (± 0.013)	0.13 (± 0.022)
Male respondents (%)	67.72	20.63
Female respondents (%)	7.14	4.50
Farmers who placed economic value on birds (%)	41.80	11.91
Farmers who believed birds have scenic value (%)	58.47***	14.81
Farmers who have extension contact (%)$^{\Phi}$	64.02	20.37
Farmers who practice irrigation (%)	48.15**	12.96
Farmers who practice apiculture (%)	16.40**	2.91
Farmers who practice livestock fattening activities (%)	11.64	2.65
Farmers who adopted agricultural technologies (%)©	50.00***	8.47
Farmers who reported shortage of fuelwood (%)	18.25	7.14
Farmers who reported presence of nursery (%)	19.31	4.23

$^{\pi}$All percentages are evaluated for n = 378; numbers in parentheses represent standard errors; ***,** and *indicate difference at 1, 5 and 10% significance level respectively. $^{\Phi}$An extension agent contacted the farm household head within the last year. ©The farm household has adopted any improved agricultural technologies, such as soil conservation, fertilizing, growing improved coffee varieties, use of improved seeds, and irrigation

[a]Ethiopian Birr (ETB) is the Ethiopian currency (1 US$ = 19.28 ETB, on 12 February, 2014 and 27.41 ETB on 26 June 2018)

exotic trees planted around homesteads (68.3%), indigenous species retained around their homes (22.2%), public forests (2.9%), timber markets (1.6%), and church forests (0.3%). In summary, the total contribution of farmland agroforestry to rural livelihoods in the study area was relatively small, indicating that there remains the potential and need for increasing the benefits from retaining these naturally occurring trees on farms.

Practice and Benefits of Farmland Agroforestry

The majority of respondents (74.9%) incorporated farmland agroforestry practices in their farming system. Fuelwood, fodder, crop harvesting activities (where

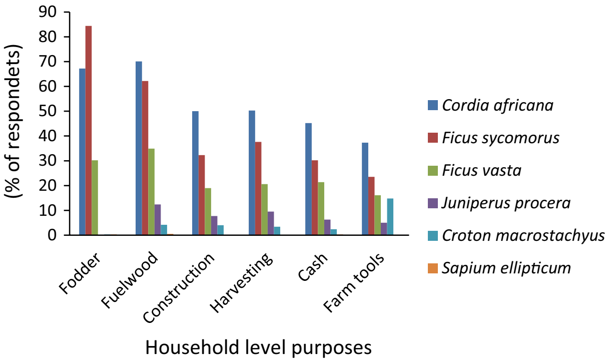

Fig. 2 Indigenous tree species on farms and their uses

branches or parts of the trees are used for piling the crop harvest, winnowing, and brushing and cleaning the crop threshing site), construction, farm tool making and cash sale were the major purposes for which farmland agroforestry was practiced by smallholder farmers (Fig. 2). *Cordia africana* and *Ficus sycomorus* were the most commonly used species that suited a wide variety of the farmers' needs. *Ficus vasta* was also used for all purposes, but less frequently than the other two species. *Juniperus procera* was only occasionally used, for all purposes except fodder, reflecting its scarcity on farmlands. *Croton macrostachyus* was mainly used for harvesting activities though it provided other benefits to farmers, including fuelwood. *Sapium ellipticum* had limited benefits, including fuelwood for household use and cash sale (Fig. 2).

Conscious efforts to retain these trees on farmlands were guided by traditional knowledge on the use of these species. Further, prior experiences with regard to the effects of these tree species on the production of agricultural crops also influenced these efforts according to farmers. Hence, the presence of the trees and their abundance were a result of the farmers' deliberate decision-making aimed at fulfilling a wide diversity of objectives on their small farms. For example, some farmers had chosen to maintain only a single tree of *Ficus vasta* on their farm because the large canopy shades crop area. Other tree species including *Croton macrostachyus* have been retained abundantly due to their small impact on crop production. Hence, farmers did not only retain tree species based on the direct material benefits the trees provide, but also on a more comprehensive assessment of how the trees integrate with the diversity of enterprises undertaken at the farm.

The farm survey revealed the importance of indigenous trees for the existence of various bird species (noted by 55.6% of respondents). These birds were valued for their economic (53.7%) and scenic (73.3%) values. According to the respondents, birds (e.g. *Anomalospiza imberbis* and *Hirundo aethopica*) had economic value because they provided services in terms of seed dispersal (32.8%) and biological pest control (21.4%). Farmers who assessed pest infestation as a major problem significantly ($t=-2.228$, $p=0.0134$) valued birds more for their economic value than those who did not consider pests as a major problem. As a result of their perception

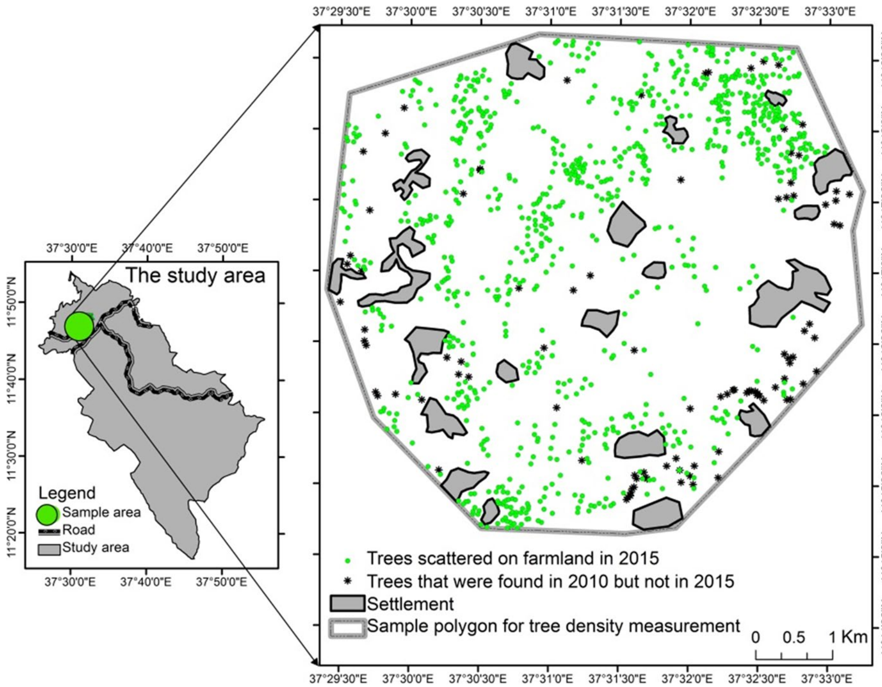

Fig. 3 Sample farmland area showing tree density and removal between 2010 and 2015

of the positive benefits of birds for pest control, 43.9% of farmers recommended increasing forest cover through afforestation or reforestation activities on specific localities for regaining these benefits from birds.

In addition to indigenous trees retained on their farmlands, farmers identified further tree species that were usually found in areas with still intact forest cover, e.g. around churches and riparian areas. These species included *Syzgium guineense*, *Ficus sur*, *Myrica salicifolia*, *Debregeasia bicolor*, *Enset ventricosum* and *Commiphora africana.* Farmers considered the existence of these indigenous species crucial for the provision of ecosystem services (e.g. soil and water conservation) in the area. The occurrence of soil erosion, increasingly erratic rainfall, migration of wild animals, and a decrease in productivity of major crops in the locality were attributed to the clearance of indigenous trees and forests (70.4% of respondents). A majority of respondents (89.7%) also attributed degradation of Lake Tana through sedimentation, retreat of lake surface area and decrease in water quality to clearance of indigenous trees.

Tree Density on Farmlands

From aerial observation of sample crop lands it was found that 65% of the farm plots did not contain trees or shrubs. The analyses also confirmed low tree density, ranging from 0.3 to 8 trees/ha, in a randomly selected major farming block (Fig. 3). However, farm plots located closer to residence areas were endowed with a relatively higher density of trees (up to 40 trees/ha). Tree density decreased with increasing maturity of the trees and distance from residence areas. As observed during the transect walks, many of the trees scattered on farmlands were between 5 and 15 m tall, mature and with branches bifurcating due to frequent lopping and pruning. As confirmed during the FGDs, trees very close to residences clearly belonged to an individual household and were more easily controlled by this household, while trees away from residences were less closely monitored by the household and also used by other villagers and herders crossing the area, and some were damaged by livestock.

From the aerial photography it was observed that tree removal occurred both in areas near to and more distant from residences. According to respondents, use for household purposes (e.g., fuelwood, construction), along with lack of alternative sources of income and absence of energy saving stoves (Amare et al. 2015) have encouraged intensive pruning and the subsequent removal of trees near residences. Also, the small average landholding size of less than 1.2 ha (Table 2) has forced the owners to clear their land for intensification of cropping activities, in some cases under irrigation. Lack of tree management, aging of the trees, destruction of trees by people and animals, or intensive commercial or subsistence use have been the causes for the removal of trees farther away from the residence, as revealed during the FGDs.

Factors Affecting the Adoption of Farmland Agroforestry

Family size, land size and experience of adopting other agricultural technologies promoted by extension agents influenced whether a household adopted farmland agroforestry (Table 3).

Family size, total land owned and adoption of agricultural technologies were positively associated with the adoption of farmland agroforestry (Table 3). A unit increase in family size increased the probability of practicing farmland agroforestry by 2.4%. Likewise, one additional hectare of land owned increased the probability of practicing farmland agroforestry by 35%. The presence of experience with the adoption of other agricultural technologies increased the probability of adopting farmland agroforestry by 13.4%. This was often related to cultivation of crops grown underneath indigenous shade trees, such as coffee, and the positive attitude and knowledge developed of the benefits of trees from the adoption of such technologies.

Factors Affecting the Number of Tree Species Adopted

The number of tree species retained was significantly affected by the number of active labor units, land size, land size on the main farming block, TLU, adoption of agricultural technologies, access to credit, and presence of a nursery (Table 4).

Table 3 Factors affecting the adoption of farmland agroforestry

Variable	Coefficient	Marginal effects
Gender	0.201	0.034
Age	– 0.002	– 0.0003
Years of schooling	– 0.045	– 0.0076
Family size	0.143	0.0244**
Total land owned	0.350	0.060*
Irrigation practice	0.084	0.014
Apiculture practice	0.487	0.083
Fattening practice	0.080	0.014
Access to extension contact	0.051	0.009
Adopted agricultural technologies	0.782	0.134***
Presence of nursery	0.123	0.021
Constant	– 0.787	

Logistic regression: LR $Chi^2(11) = 34.61$; $Prob > Chi^2 = 0.0003$; Log likelihood = – 195.80351; Pseudo $R^2 = 0.0812$; No. of observations = 378; ***, ** and* indicate significance at 1, 5 and 10% levels, respectively

Table 4 Factors affecting number of tree species to retain

Variable	Coefficient	Std. Err.
Age	0.001	0.004
Years of schooling	– 0.009	0.018
Active labor force	0.062	0.027**
Total land owned	0.15	0.076**
Land size on the main farming block	– 0.19	0.099*
Irrigation practice	0.077	0.085
Pest is a problem	0.022	0.077
TLU	0.022	0.013*
Apiculture practice	– 0.016	0.091
Access to extension contact	– 0.042	0.106
Adopted agricultural technologies	0.318	0.082***
Access to credit	0.178	0.077**
Presence of nursery	0.201	0.087**
Economically valued birds	0.085	0.076
Constant	– 0.070	0.182
/lnalpha	– 17.58	724.97
Alpha	2.44e-08	0.00002

Negative binomial regression: LR Chi^2 (14) = 78.05; Dispersion = mean; $Prob > Chi^2 = 0.0000$; Log likelihood = – 641.93278; Pseudo $R^2 = 0.0573$; Likelihood-ratio test of alpha = 0: Chibar2 (01) = 3.6e-05 Prob > = chibar2 = 0.498. No. of observations = 378; ***, ** and *indicate significance at 1, 5 and 10% levels, respectively

The expected log count of the number of species retained increases by 0.062 for a one-unit increase in the number of active labor force in a family (Table 4). This was linked to the availability of labor for maintenance of trees, amount of tree products consumed by the household (e.g. fuelwood), or the need to complement farming activities with alternative income. The number of species retained increased by 0.15 and 0.022 for a one-unit increase in land size and in TLU, respectively (Table 4). It is likely that the correlation of land size and number of species retained was driven by small average plot size and spatially fragmented land possession, i.e., farmers owned plots of land in different places and landscapes (e.g. near to riparian areas, church forests) increasing the probability of tree species variability.

A one-unit increase in the TLU of a household increased the likelihood of retaining multiple tree species by 0.022. This was linked to the need to feed livestock in different seasons, or different types of livestock with different feed requirements. In contrast, a one-unit increase in land area in hectare in the main farming block decreased the number of indigenous tree species retained by 0.19. This suggests that more uniform environmental conditions on the land plot, as well as the increasing suitability of the land for more intensive farming, decreased the number of tree species retained on the major farming block. Access to credit and the presence of a nursery increased the number of indigenous tree species retained by a household by 0.178 and 0.201, respectively (Table 4). Yet, as revealed during the tree nursery inventories and FGDs, most of the nurseries produced few seedlings of indigenous tree species, focusing on exotic tree species in response to demand by farmers and governmental policies.

Discussion

As reported by the farmers in Dera *Woreda*, six indigenous species mainly formed the tree component of the local farmland agroforestry practice. These species are used for shade, feed, nutrition, timber, fuelwood, cash income, environmental services, and cultural ceremonies, which illustrates the broad contribution farmland agroforestry makes to local livelihoods. In addition to the uses documented by respondents, all these species are known to be suitable for a variety of food and medicinal uses due to their nutritional, pharmacological and phytochemical compositions (as reported by Asrie et al. 2016). However, this study did not find evidence that such potential uses are considered by respondents.

What differentiates farmland agroforestry from other agroforestry practices is that the species diversity of farmland agroforestry is relatively low and its vertical structure simple, particularly when compared to home gardens. Also, farmland agroforestry does not require intensive management given that tree species naturally regenerate from the soil seed bank and only need minor care. While this may be an advantage from a cost perspective, farmers typically do not perceive the practice of retaining indigenous trees is a management or conservation priority. This lack of appreciation distinguishes farmland agroforestry from other agroforestry practices, which require farmers to take deliberate action and often to introduce the desired species. The low explanatory power of regression models presented in Tables 3 and

4 is a manifestation of this fact. It is also speculated that with the continued degradation of the agroforestry system the management efforts to maintain farmland agroforestry will exponentially increase, as for example changes of microclimate, intensified browsing pressure or further impoverishment of the soil seed bank will reduce natural rejuvenation of the remaining indigenous trees.

The findings with regard to the socio-economic characteristics of adopters of farmland agroforestry, as well as the determinants of adoption, are in general consistent with those for other agroforestry practices. For example, the results confirm earlier findings that reported the existence of a positive relationship between family size and tree cultivation by farmers (by Fahmi et al. 2015), farmer-managed natural regeneration of trees (of Iiyama et al. 2017), and total number of tree species cultivated (Abiyu et al. 2016). Also, the results are consistent with studies that found a positive relationship between farm size and the regeneration of trees (e.g. Iiyama et al. 2017), and number (Abiyu et al. 2016) and abundance of tree species (Endale et al. 2017). Furthermore, support is provided for studies reporting positive relationships between the adoption of agroforestry practices and other agricultural innovations (e.g. Gyau et al. 2015), the number of tree species planted and labor availability (Abiyu et al. 2016), as well as agroforestry adoption rate and labor availability (Etshekape et al. 2018). This apparent congruence may at least partially be explained by the fact that some of the earlier studies have included occurrences of farmland agroforestry in their observations without distinguishing this practice from other forms of smallholder agroforestry.

The strongly positive relationship of adoption of farmland agroforestry and number of tree species retained with adoption of other agricultural technologies was mainly related to the occurrence of agricultural crops that tolerate or even require some shade, such as *Coffee arabica*, *Carrisa papaya*, *Catha edulis*, *Rhamunus prinoides* or *Mangifera indica*. The promotion of such crops could thus—along with the increased integration of local farmers in national and international agricultural markets—contribute to the survival and proliferation of farmland agroforestry in the study region.

Despite the recognition of the multiple benefits of this practice by farmers, their willingness and ability to sustainably manage and conserve farmland agroforestry systems seemed low. The haphazard retention of naturally occurring trees and their frequent elimination for agricultural intensification and cash may in part be due to lack of appreciation of farmland agroforestry by government agencies and extension services. The absence of a significant correlation between extension contact and adoption of farmland agroforestry or tree species diversity can be interpreted as manifestations of this point. While the presence of a local nursery was in principle positively related to tree species diversity in farmland agroforestry, their predominant focus on production of exotic fast-growing timber species illustrates a lack of recognition of traditional agroforestry practice in current governmental development interventions and policies that are primarily geared towards increasing agricultural production, as has been noted by others (e.g., Tefera et al. 2014).

Spatial analysis revealed that the density of trees on farmland declined in particular in the more remote areas of village land that are less under control of individual households, and observation confirmed that trees in such areas are frequently damaged and of poor quality due to frequent lopping, browsing or pollarding. While individual household-level variables are important determinants of farmland agroforestry practices, this result also indicates that the current legal framework and tenure system does not provide sufficient incentives and mechanisms for farmers to retain, protect and sustainably manage the ecologically valuable indigenous trees on their farms. This finding is in line with other studies (including Amare et al. 2017b) confirming the importance of effective governance mechanisms and institutions in the context of natural resource management. In order to protect the remaining trees, regulations more clearly defining allowable management practices and the effective enforcement of existing land ownership exclusion rights will be necessary.

Conclusion and Policy Implications

A systematic review of the recent literature indicated the existence of a conceptual ambiguity and lack of analytical rigor with regard to distinguishing the purposeful retaining of indigenous trees on farmers' cropland as a separate agroforestry practice. This led to an inaccurate assessment of the practice in previous studies. The purpose of the paper was to describe and analyze the practice, benefits and determinants of farmland agroforestry in Dera *Woreda*, thereby contributing to an improved analytical understanding of this practice as separate from other agroforestry practices.

Despite the fact that farmland agroforestry is an integral part of the livelihood portfolio of rural households in Ethiopia in terms of income and maintenance of other farm resources (e.g., livestock) it's total contribution to rural livelihoods in the study area was relatively small. The spatial analysis confirmed the decline of this practice associated with increasing pressures towards agricultural intensification, even though farmers clearly acknowledged the importance of indigenous tree species on their farms for biodiversity and the provision of ecosystem services.

This study illustrates the trade-offs and conflicts farmers, extension agents, governmental decision-makers and other stakeholders typically face with regard to environmental conservation and agricultural intensification and development objectives. While farmland agroforestry is linked to important environmental and biodiversity benefits, the economic benefits are relatively low and not greatly appreciated by farmers. As a consequence, the individual farmers' land use decisions increasingly replace this traditional agroforestry practice intentionally or unintentionally. In order to maintain farmland agroforestry in the long term it will be important to increase the benefits smallholder farmers derive from this practice compared to the costs they incur in order to produce the environmental services and other societal benefits. Fostering value adding of tree products suitable for higher value uses, such as processed foods, cosmetics, or herbal medicines may constitute important aspects in this regard.

The findings indicate a need to undertake further studies on farmers' decisions about whether to maintain or abandon traditional agroforestry practices, as well as to optimize their technical, socio-economic and environmental performance. This includes research on factors affecting management and conservation choices and species preferences, valuation of environmental and socio-economic benefits of farmland agroforestry, improved farming practices to increase economic viability of native tree species, and effective institutional and governance arrangements for their management. In addition, extension interventions are required to help conserve, re-establish, and sustainably manage indigenous trees on their farmlands.

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