UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

COURSE: INTERDISCIPLINARY LAND USE AND NATURAL RESOURCES MANAGEMENT

What are the ecological, economic, and cultural effects of agroforestry practices on small farms, given the trend of land fragmentation?

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Abstract

Agroforestry is the predominant agricultural system practiced by smallholder farmers in Gakina, a village in the central highlands of Kenya. Trees are grown in combination with food and cash crops in order to meet household needs for food, fuelwood, and timber, and earn income. Farms are small, and decreasing in size as they are subdivided via inheritance. Land fragmentation has the potential to threaten livelihoods and food security, and forces farmers to prioritize food, fodder, cash crops, and trees to make the best use of limited space. Whether and how decreasing land size shapes agroforestry practices, and the effects of having trees on farms was the focus of this study, which used a combination of social and natural science methods.

Our findings show that trees are important on small farms. Tree density increases as farm size decreases, and many farmers report self sufficiency in food and fuelwood. This may be due in part to the preference for fast growing exotics, which can produce abundant timber and fuelwood in a short timeframe. However these trees are not without trade-offs, as they displace indigenous trees, and can have negative effects on crops, water, and soil. The preference for exotics demonstrates local attitudes favoring economic value over cultural value, which is being lost in the transition. There is limited understanding of the ecological effects and potential of agroforestry, resulting in a conflict between trees and crops. Multipurpose trees are underutilized, which may represent a missed opportunity for increased livelihood and farm system diversification.

Keywords: agroforestry, self-sufficiency, multipurpose trees, land fragmentation

Table of contents

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Introduction

Description of study area

The study area of this investigation is the village of Gakina, northwest of Karima forest, near the town of Othaya, in Nyeri district, in Kenya. The area is characterized as tropical highland with an elevation of 1,850 meters. The average annual temperature is 16.8 °C. Average rainfall is 1,401 mm per year. Rainfall is bimodal, with bigger rains in April and May and smaller rains in October and November (climate-data.org, 2016). The predominant soil type in Othaya is Humic Nitisol (FAO, 1997). The population of Othaya is approximately 19,000 people. The majority of inhabitants (73%) live in rural areas, whereas the other 27% live in Othaya town (Kenya National Bureau of Statistics, 2009). The agro-ecological zones of the area are characterized by the FAO as upper midland 1, and upper midland 2, with key crops including coffee, tea, maize, beans, peas, irish potatoes, arrowroot, and sweet potatoes (Pinard 2014, FAO 2016). Many keep dairy cattle in cut and carry systems, where fodder crops such as napier grass are also present (Tengnäs, 1994). Coffee is the major cash crop in Gakina (Muturi, 2015).

Introduction of agroforestry in the study area

Definition of agroforestry (AF) and description of AF systems

The majority of farming systems in Othaya incorporate trees. Agroforestry, or farm forestry is defined as "*... a land use system in which trees or shrubs are grown integrating with agricultural crops, pastures or livestock. Generally the system is characterized by the economic and ecological interaction between the components within the agroforestry system*" (Tengnäs, 1994, pg.1).

Agroforestry systems in Nyeri district can be classified into three general categories: woodlots, boundary plantings, and mixed systems (Pinard et al. 2014). Woodlots are systems with at least a portion of the farm area dedicated entirely to tree production for timber or fuelwood. Boundary agroforestry systems are those where trees are planted in rows at close spacing with subsequent thinning of young trees for poles, and the rows of established trees demarcating property lines or agricultural zones, serving as windbreaks, and providing fuelwood through regular pruning and pollarding. Mixed agroforestry systems are those in which trees and crops are combined within the system (Tengnäs, 1994).

History of tree planting and agroforestry practices

Agroforestry systems have been shaped by the connection between land ownership and historical tree planting. Boundary trees are common Kikuyu culture and emerged from increasing population pressure in Kikuyu areas as a mean of marking land, to prevent boundary disputes or following disputes over sub-clan land (Dewees, 1995). During colonial times, tree nurseries were established to support needs of colonials for tree products, which was unpopular by local population, and unsurprisingly the whole system collapsed after the Mau Mau revolt in 1950s (Castro, 1993). On farms, during colonial times people were not planting trees because they had no ownership over the land. After independence (1963) land ownership increased and people started investing efforts in their land, e.g. by planting trees. Furthermore the government supported people in tree planting on their farms Castro (1993). More recently, the presence of the Green Belt Movement (GBM) in the area has promoted environmental conservation, climate resilience, and encouraged women to plant trees (Green Belt Movement, 2016). Arguably, this probably influenced farmers mindsets, and has affected agroforestry and tree planting practices.

Influence of land tenure and inheritance rules on agroforestry

After the colonial era, when land consolidation was not longer enforced, land management quickly returned to subdivision due to inheritance. The common rule is for the father in the household to decide how the land will be distributed, and usually this means that it is split equally among the sons (Christiansson, 1988). In addition to mentioned inheritance rules, inherited land cannot be sold without the consent of the other members of the family owning land, limiting the availability of land for purchase (SLUSE 2016 Climate Change Group[1], personal communication). Such land tenure in the area affects the size of the farms (Shreffler and Nii-Amoo Dodoo 2009, Christiansson 1988).

People in the past used trees as means of claiming ownership of land, as explained by Haugerud (1989) farmers in Embu, Kenya refused to plant trees although they were distributed for free by the colonial government, with fear that government would claim their land. The connection between trees and land ownership is still prevalent in the community, considering the prohibition of tree planting on rented land by the landlords (Haugerud 1989, SLUSE 2016 Climate Change Group[1]). As stated by Appiah and Pappinen (2010), trees give the feeling of security in land ownership, where on rented land, trees are absent.

Agricultural intensification and agroforestry

With decreasing farm sizes, farmers need to maximize the output of their farming practices. Due to reduced farm size people are becoming more dependent on non-agricultural income sources and seasonal employment (Ovuka 2000). Input prices, expenses for social services, and school fees are simultaneously increasing, complicating the life of farmers (Oeba et al., 2012). For the farmers, trees can provide multiple needs: food, fuelwood, charcoal, fodder, income, medicine, shade, shelter, timber, as well as ecological benefits (Appiah & Pappinen, 2010; Tengnäs, 1994). Trees also serve as a safety net by diversifying income sources (Appiah & Pappinen, 2010; Tengnäs, 1994). Household self-sufficiency in timber and fuelwood eliminated the need off-farm work to provide income for these expenses, and tree products themselves can be a source of income (Appiah & Pappinen, 2010).

Intensification can lead to farmers preferring exotic trees due to their ability to provide short-term cash income, fuel and shade (Appiah & Pappinen, 2010). Eucalyptus is a prime example of this preference, which serves as a fast source of fuelwood and is extensively grown despite the poor wood quality, negative impacts on soil, and intensive use of water (Addis, 2009). The literature indicates that other, potentially very useful, indigenous species are often not used by farmers despite their presence (Pinard et al. 2014; Appiah & Pappinen, 2010). It must be kept in mind that attitudes, preferences, and on-farm decision making are influenced by a complex interaction of perceptions, factual knowledge, society, environment, and sharing of information (Meijer 2015).

The knowledge gap we want to investigate is how land fragmentation in affecting agroforestry practices.

Problem Statement

Based on the reviewed literature, gathered knowledge and understanding of the agroforestry system, and the agreement in literature that land fragmentation is taking place in our area of study, we make our hypothesis that decreasing farm size is affecting agricultural practices, and that this changes will have an effect on decision making, livelihoods and the community in general. This leads us to the following problem statement:

What are the ecological, economic, and cultural effects of agroforestry practices on small farms, given the trend of land fragmentation?

To answer this, four research sub-questions are consulted:

1. What do agroforestry systems look like?
2. Which factors are shaping the system?
3. What are the ecological effects of changing agroforestry systems?
4. What are the socioeconomic and cultural effects of changing agroforestry systems?

Methodology

To gain a deeper understanding of the farming system in the area of the study, various multidisciplinary methods were applied, including grand tours, field semi structured interviews (SSI), questionnaires, focus group discussion, soil sampling, temperature and humidity measurements, remote sensing, and GPS measurements. The tabular overview of applied methods can be found in Table 4 in Appendix I.

Grand tours

Three explorative tours were taken in the Gakina area (Figure 1), provided by two local guides and an elder from the village. The routes of the tours covered the study area evenly, covering all main roads connecting the villages under study. Information gathered on tours included information about local trees in the area including their local names, an overview of land use distribution, identification of farming practices, and a general cultural orientation and social introductions. In addition, the elder served as a key informant, providing a historical overview on land tenure and connections between land ownership and tree planting, and also facilitated interaction with farmers that were approached for questionnaires and semi-structured interviews. The local guides assisted as interpreters in the entire methods of data collection.

Sampling and Reflection

The guides and elder were not purposefully selected, but assigned to the study and pre-selected, presumably according to the criteria of English level and community standing in the case of the guides, and civil appointment in the case of the elder. Alternatives were not pursued due to time constraint of the study, however all made valuable contributions to the study, including the contrasting perspectives of younger and older generations, and differing status.

Focus Group Discussion

One focus group discussion (FGD) was held with seven farmers from Gakina and adjacent areas. Females outnumbered males six to one, with ages ranging from 28-74. Five main questions were posed, which were centered on land tenure, tree use and perceptions, and common challenges (Appendix II). Responses were recorded on large posters, field notes, and by dictaphone. Participants were encouraged to respond to questions in a free format, but according to their individual farming practices and not "common knowledge".

Sampling and Reflection

Participants were selected via a combination of convenience and snowball sampling, during tours and after a church service. The disproportionate representation of females to males may be a result of this strategy, as women were more often available, near their households, or attending church. The majority of the men invited did not attend. The community mapping exercise which was previously planned was not conducted due to the reluctance of the participants, as some of them were from different villages than the study area. The differing villages of participants may present an error in the data collected, as responses were site-specific, and therefore could represent conditions that differ from those of the study area. However, responses seemed consistent between participants from Gakina and outside. Interestingly, data collected from the FGD often contradicts that of interviews and questionnaires, which may reflect the norms of the community, as opposed to individual opinions and attitudes.

Questionnaires

To gather information from the largest number of respondents possible during the limited time in the field, a questionnaire was distributed to provide standardized information. The aim was to obtain basic demographic information, an overview of agricultural practices, details about trees (presence, abundance, configuration, and purposes), livelihood information, and values related to agroforestry. A total of 30 questionnaires consisting of 18 questions were filled with the assistance of interpreters (Appendix III). To ensure comprehension, the questionnaire was administered individually, in the local language.

Sampling and Reflection

The sampling strategy for questionnaires was to select every fifth house along the roads going through the area of the study. In order to represent the studied area evenly, roads were selected with the help of detailed satellite images. The exception to this strategy were the first seven respondents, which were those willing to participate after a church service. This was done to verify the questionnaire. The sample consists of 60% female and 40% male respondents which shows nearly equal gender distribution. The age of respondents was between 18 and 95, with a mean age of 51. Most of the respondents had upper primary or secondary education (Figure 19 in appendix IV).

As opposed to the semi-structured interviews, the questionnaire relied on reported information about farms, which could be inaccurate. This was a trade-off we made in favor of having a larger sample size. The data was triangulated and combined with that of the SSI's where possible. Occasionally, premade farm typologies did not fit with reality, so coding had to be adapted in the field. Often answers such as those about land transfer or farm history contradicted each other and could not be clarified, which shaped the results.

Field Semi-structured interview (SSI)

To obtain data on individual agroforestry practices, semi-structured interviews (SSI) were conducted with nine farmers by walking with them and observing their fields. Both broad and targeted questions were posed in order to target changes in land size, agroforestry practices, specific trees, challenges, and support (Appendix V). Data from SSIs was triangulated with questionnaire data where possible. Shannon index values on tree diversity and evenness were extracted from interviews, as well as questionnaire data. SSI's were combined with soil sampling on five farms, and with temperature and humidity measurement on one farm.

Sampling and Reflection

In order to achieve even spatial distribution and a representative sample, farms were selected randomly, as with the questionnaires, inquiring at every fifth household along each of the main roads in the villages under study (Figure 1). Sometimes there was difficulty in ensuring comprehension of questions When analyzing data, some differences in the outputs of the different SSIs can be identified, showing the nature of the semistructured interview not providing coded information. The decision to do the SSI in field with the farmers can be concluded to work well, as reporting from recollection does not always correspond with reality. Much information was obtained through observations during field walks. This can also gives concern to information gathered off-farm, e.g. via questionnaires.

Natural science methods

The purpose of natural science methods was to investigate the effects of trees on soil and microclimate. This includes the study and analysis of soil profiles and characteristics and microclimate using temperature and humidity sensors. We investigated three systems within a farm; woodlot, tree-crop mix, and sole crop plots to compare effects of trees. Furthermore, species configuration on the farms were inspected and GPS was used to map and validate the quality of the data.

Soil sampling and analysis

For soil sampling five farms (1 through 5 on map in figure 1) with similar topography located within the same neighborhood (Figure 1) were selected. The soil samples were taken from all three systems from each farm selected. In those three systems, woodlot represents grevillea woodlot, tree-crop mix represents grevillea and maize and sole crop represents maize, most of which were intercropped with beans and potatoes. We decided to exclude farm 5 of the five sampled farms for analysis, as the species in the farm system was contrasting to the other samples, which had napier in sole crop plot and eucalyptus in woodlot.

Volumetric rings of 100 cm^3 were used for to take soil samples from the A-horizon (20 cm depth) at five different farms, and for each systems. At each plot within the investigated farms, 3 replications were made. At farm 1 three profiles at 100 cm depth were made in the three investigated systems, and samples were additionally taken from the B-horizon (60 cm depth).

The soil samples were taken to the soil lab of the University of Copenhagen, Denmark and oven-dried for further analysis. Bulk density and dry weight were calculated from each sample. Total carbon (C) and nitrogen (N) content, and C:N ratio was analyzed as described by Sørensen and Bülow-Olsen (1994). Permanganate Oxidizable Carbon was analyzed according to Weil et al. (2003). Texture was identified according to FAO (2006).

Sampling and Reflection

Time, laboratory time and instruments available as well as dividing time for other methods in field was a constraint for analyzing additional parameters and having more replications. Making profiles on more than one plot and having samples from B-horizon from more plots could have contributed to more precise results and possibly affect the interpretation of the results. Also, having more samples from each plot could have contributed to the findings. We could have chosen to do auger samples to get more samples, and samples from deeper in the soil or composite sampling. It can be discussed whether composite sampling could have increased the representativeness of the samples from each plot compared to one site. At the end, volumetric rings sampling were chosen as a compromise between getting a large amount of samples from each plot and getting samples useful for bulk density and N and C content in mass per volume (Figure 21, 23, and 24 in Appendix VIII).

Due to the heterogonous nature of soil distinguishing natural soil differences and the influence of the farm systems are difficult and when interpreting results this needs to be factored. In general, it was not difficult to identify farms with the three investigated systems since these were abundant in the area. The soils were overall very similar and comparable, but comparability of the farms can be discussed. Local differences in the landscape topography was present, the area being sloped complicating comparison of the different farms. Identifying farms with the three investigated systems within a certain proximity to ensure the soil to be as identical as possible caused some problems due to the different nature of the farms. Furthermore, there were slight differences in the woodlots, with farm 2 having some Eucalyptus trees, the woodlot of farm 4 also being mixed while farm 1, 3 and 5 were mainly Grevillea.

Due to night-rains and soil samples being taken different days, measuring the the soil moisture with tensiometer as planned was skipped as the comparability between plots were doubted. The process of drying the soil in the field environment prolonged the process of drying, which may have influenced the analysis results, though evidence of that was not found.

The MnoxC and pH measurements had large variations between replicates, resulting in higher standard error. This variation is the result of the quality and calibration of the instruments used, the laboratory protocol itself, and the experience of the personnel. Despite the variation, there is a significant correlation (r=0.749) between MnoxC and the total carbon, mutually validating % C and MnoxC results (Figure 26).

Temperature and humidity

Temperature and humidity was measured using Maxim's iButton® sensors (Maxim Integrated, 2016) on farm 4. Three iButton® were placed in each of the three investigated systems where the soil samples were also taken. They were placed in 1 m height. The sensors recorded temperature and humidity every 10 minutes for 72 hours.

Sampling and Reflection

The limited number of sensors available was a constraint for us from using them in several places, which could have been good for data validation and comparison. For humidity there is only one measurement in each investigated system.

Species identification, configuration and diversity analysis

Identification of species was done by determining scientific names by looking up mentioned local name in the literature, as done by Pinard (2014). To verify, basic botanical characteristics, tree uses, and general descriptions were compared to the *Field guide to common trees & shrubs of east Africa* (Dharani 2002). The species configuration was investigated by using data from questionnaires and SSI on tree species and number of different tree species per farm. Data was verified by observations during the SSI From this data the Shannon diversity index and Shannon evenness was calculated for each farm (Shannon and Weaver 1949).

Sampling and Reflection

Limitations to this are the lack of confirmation on numbers from the questionnaire as not all farmers from questionnaire were addressed at their homestead. Tree age, and use of circular sampling to represent the farm was planned before fieldwork but was not used because it was impossible to make a sample that represents the farm. Whole farms were considered instead. Tree age was not estimated based on diameter at breast height (DBH) dues to time constraints and lower priority.

The configurations of trees on the farm were categorized as woodlot, boundary, mixed, near household, and other. However, in reality, the clear distinction between these categories does not exist. There is a whole variety of configurations between sole crop, trees mixed with crops and woodlot. Boundaries can often be difficult to distinguish from woodlots, and number of trees mixed with crops varies greatly.

Global positioning system (GPS)

The device used was Garmin 62s handheld GPS device (Garmin, 2016). GPS waypoints were collected for all SSI, soil sampling sites, and temperature and humidity sensor locations (Figure 1). Tracks were recorded on the Grand Tours. The GPS was used for validation of the reported farm sizes with perimeter walks on three farms, especially the ones which would have been hard to confirm using the satellite image.

Sampling and Reflection

The only limitation identified for the use of GPS was the fact that we only had one device, e.g. resulting in not all farm perimeters being measured.

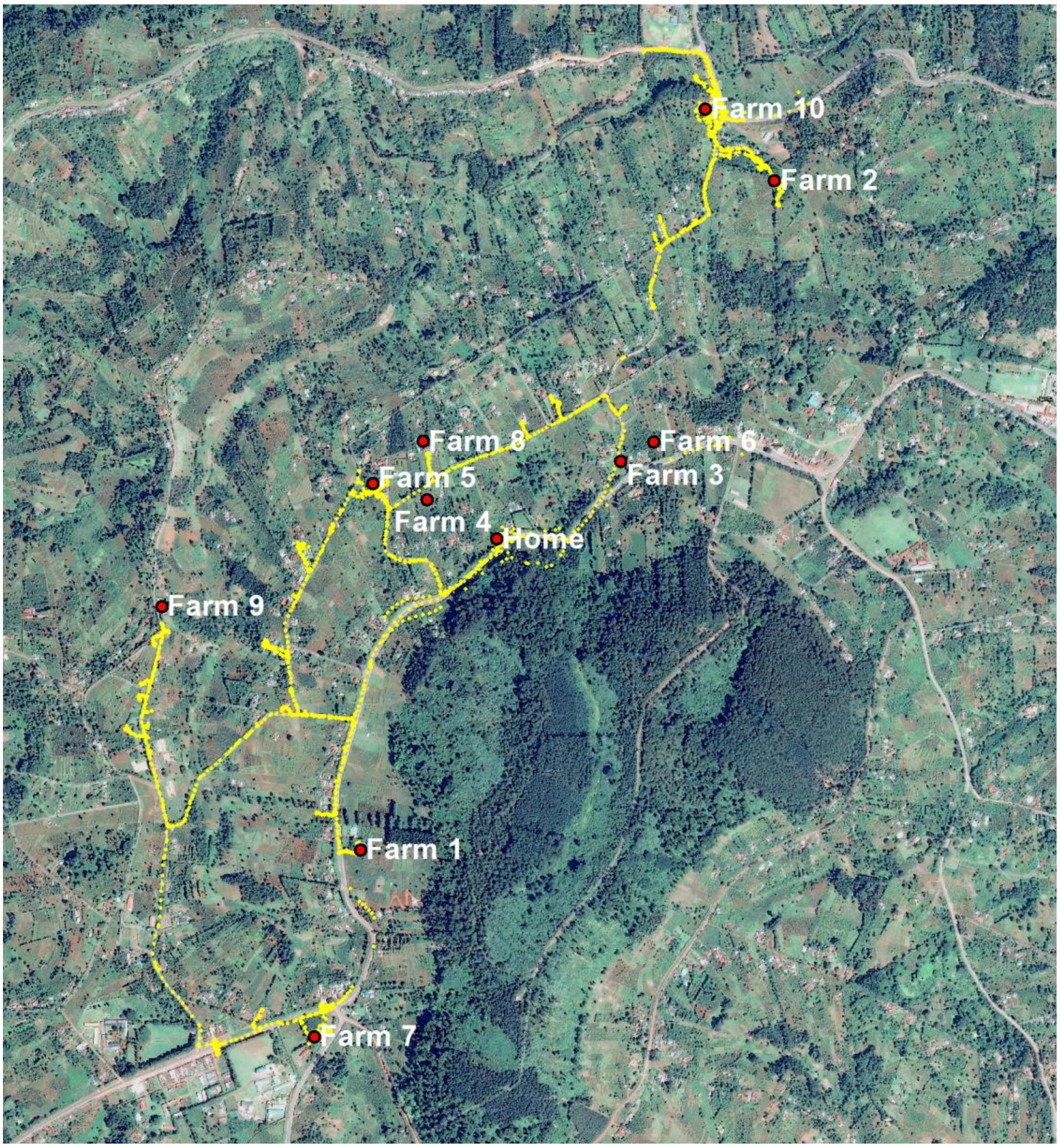

Figure 1 Map of the investigated area. Farms used for interviews, soil and microclimate data are red dots, the grand tours are the yellow markings. Source for imagery: Google Earth, 2016.

Results

What do agroforestry systems in Gakina look like?

Land ownership and land renting

Land ownership are framing agroforestry practices. Farms are mostly inherited (94%) and no farmers purchased the farm. The predominant practice in land ownership is that, upon inheritance, the ownership is lifelong. Some farmers also rent additional land. According to FGD, renting of land is increasing due to insufficient farm size and need for more space for food, fodder, and cash crops. 3/9 interviewed farmers rent additional land, at 0.4ha, 0.8ha and unknown size respectively. Land is usually rented in small pieces by people owning more land than they can manage or people incapable of farming due to age or health problems. Trees are usually not planted on rented land. As stated by grand tour informants, it is due to short renting periods so trees are not appropriate investment due growth time. Also tree planting is discouraged by landlords. Our observation from the field with almost no trees on rented land supports these claims.

Farm size

In the sample of 39 farms, farm size varied between 0.05 and 4.0 ha, with the mean size of 0.76 (±0.20ha). When categorized by area, 62% of the farms are below 0.5ha, 13% between 0.5 and 1ha, and 26% larger than 1ha. Mean area per person is 0.21ha (±0.034ha). In the FGD all participants agreed that farm size is a limiting factor to agricultural activities, however, it was not identified as a main problem either in FGD, questionnaires, or in SSI's.

As hypothesized decrease in farm size is happening in the area. Compared to previous generations 72% of the farms decreased in size, 28% stayed the same, and no farms gained land. The mean size of the farm across two generations back is shown in Figure 2. In addition, positive moderate correlation ($r=0.649$, $p<0.001$) was found between farm size and area of land per person in the household meaning larger farms have more land per person.

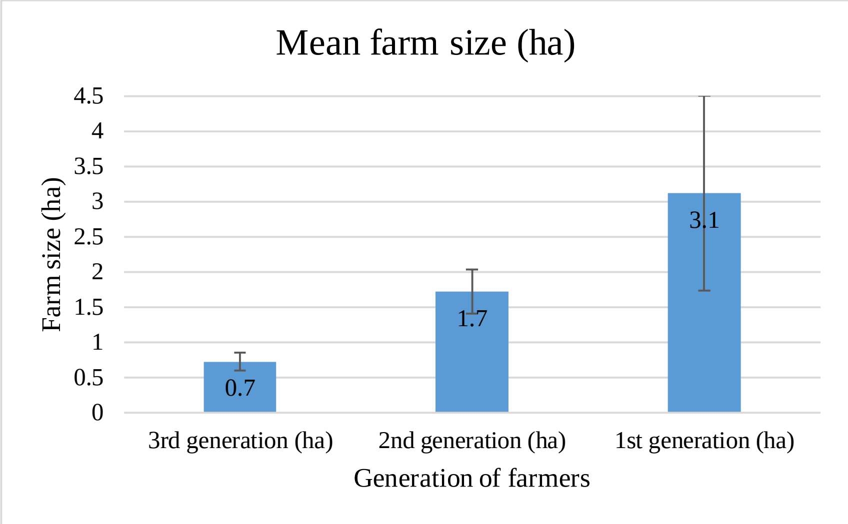

Figure 2 Mean farm size among different generation of farmers, 1st generation being the furthest in the past.

The change in farm size relative to current farm size allows comparison between farms of different size (Figure 3). On average, farms are now 5.3 times smaller than in the previous generation, and 7.6 times smaller than two generations back. Farms continue to decrease in size, as explained by an interviewee his 0.4 ha land will be divided among five sons along with his five daughters if they do not get married.

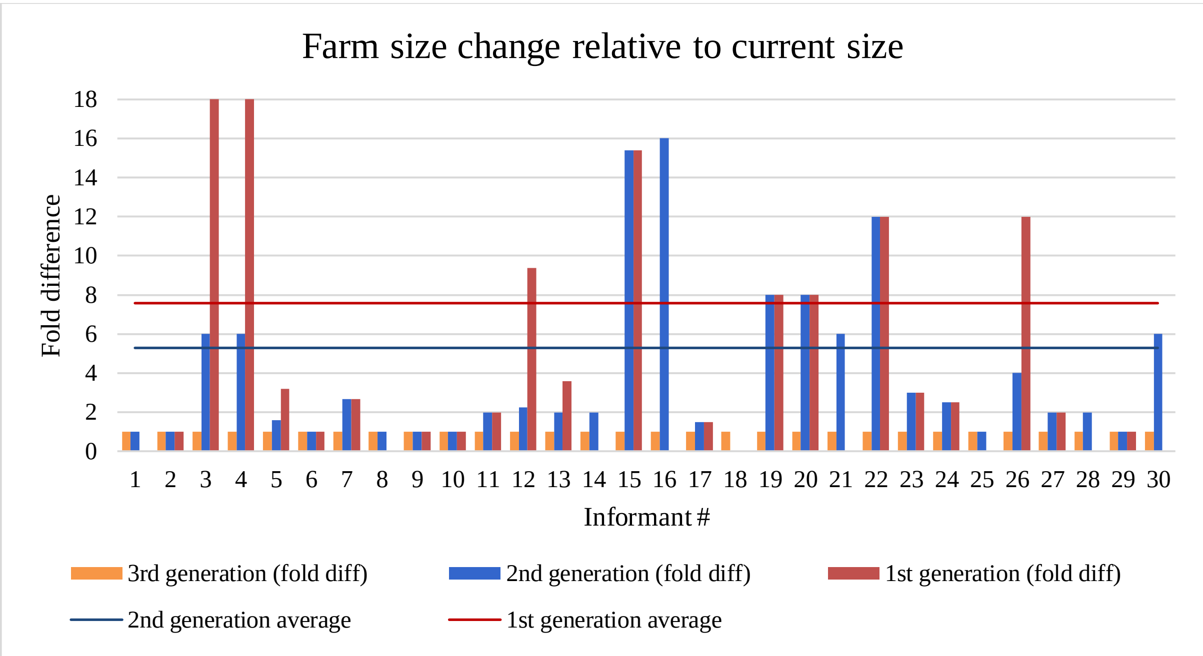

Figure 3 Change in farm size among three genaration in the past. The Y axis represents the fold difference in size, relatie to current size of the farm (3rd generation). Horizontal lines represent average size change.

Relationship between land size and agroforestry practices

A positive correlation between farm size and abundance of trees (0.668) were identified. However, looking at the tree density in relation to farm size, it is clear that small farms (<0.5ha) have significantly more trees per unit of area compared to larger farms (Figure 4).

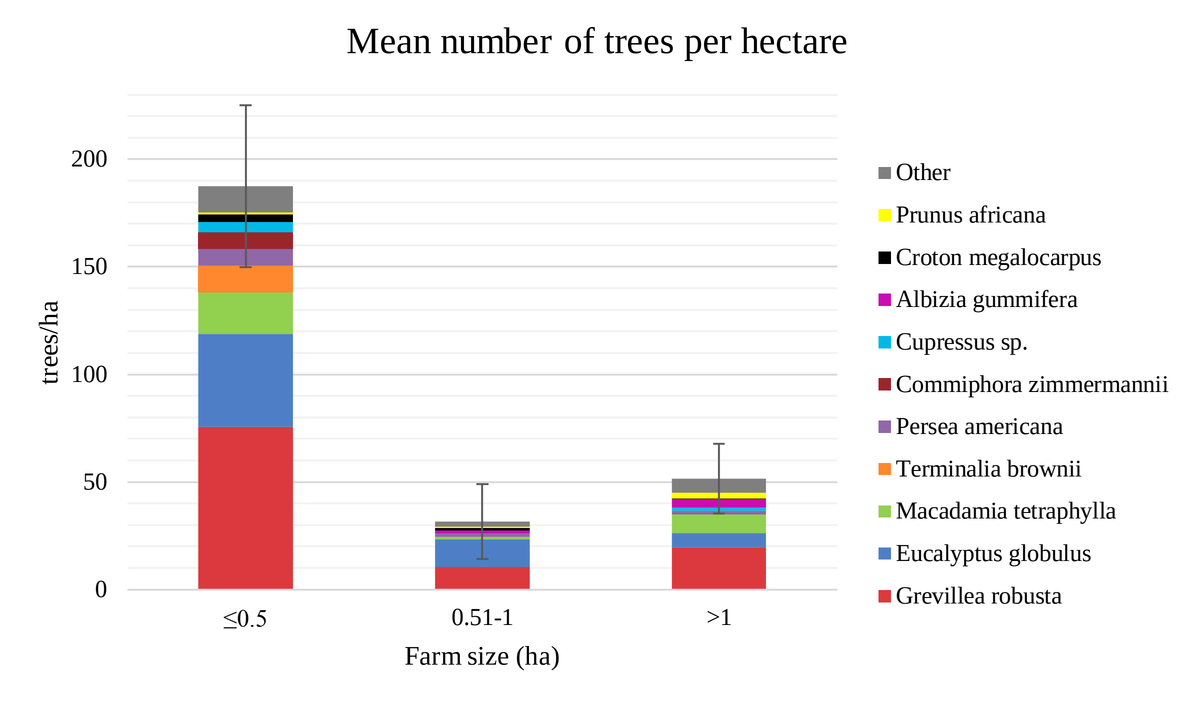

Figure 4 Mean number of trees per hectare in three farm size categories. Within the bars, mean number per species is illustrated.

Trees

Based on the data from the SSI and questionnaires, 89% of farms have trees, showing that agroforestry is predominant type of farming in the area. Most commonly present trees and most common purposes as reported by farmers are presented in the table 1. The complete list of trees can be found in appendix VI.

Table 1 List of top 10 tree species by abundance, with shown reported purpose and configuration. I/E shows if species is indigenous (I) or exotic (E), based on the literature.

Species	Tree occurrence	I/E	Purposes and % of farmers	Configuration
Grevillea robusta	85%	E	Fuelwood (93%); Timber (86%); Mulch/Manure (24%); Income (17%); Shade (10%); Erosion control (3%); Support for Crops (3%)	Mixed (74%), Boundary (21%), Woodlot (11%)
Persea americana	62%	E	Fruit (100%); Income (48%); Charcoal (5%);	Household (50%), Mixed (42%), Woodlot (8%)
Eucalyptus globulus	62%	E	Fuelwood (95%); Timber (85%); Income (20%); Mulch/Manure (10%);	Woodlot (50%), Mixed (36%), Boundary (21%), Household (7%)
Macadamia tetraphylla	56%	E	Fruit (79%); Income (68%); Fuelwood (5%); Timber (5%); Shade (5%);	Mixed (78%), Woodlot (22%), Household (11%), Other (11%)
Mangifera indica	38%	E	Fruit (100%); Income (38%);	Mixed (60%), Household (40%), Other (20%)
Prunus africana	21%	I	Timber (43%); Fuelwood (29%); Charcoal (29%); Support for Crops (14%);	Woodlot (67%), Mixed (33%)
Croton megalocarpus	21%	I	Fuelwood (100%); Charcoal (57%); Timber (14%); Fruit (14%); Support for Crops (14%);	Mixed (67%), Woodlot (33%)
Cordia africana	18%	I	Timber (83%); Fuelwood (50%); Fruit (17%); Support for Crops (17%); Shade (17%);	Mixed (80%), Woodlot (20%), Boundary (20%)
Cupressus sp.	15%	E	Timber (100%); Fuelwood (80%);	Mixed (75%), Boundary (50%)
Zanthoxylum usambarense	15%	I	Fuelwood (50%); Fence/Boundary (25%); Feed/Fodder (25%); Support for Crops (25%);	Woodlot (100%)
Croton macrostachyus	15%	I	Fuelwood (100%); Timber (25%);	Mixed (50%) Household (50%)

The five most occurring trees are all exotic species. Regarding purposes, trees are mostly used for timber, fuelwood and fruits. The tree with most purposes is *Grevillea robusta* used for subsistence fuelwood, timber for household use or sale, for mulching/manure, and to lesser extent as shade, erosion control, and support for crops.

The first five trees listed during the FGD were *Cordia Africana*, *Grevillea robusta*, *Croton megalocarpus*, *Eucalyptus globulus* and *Acacia maersnii* which are not the same species as top species by occurrence or preference when people were asked individually. *Grevillea robusta*, *Eucalyptus sp*, and *Croton megalocarpus* are common, but *Acacia maersnii* is not in top 10 species by occurrence (Table 1). To investigate the diversity of trees, Shannon diversity index for trees was calculated for each farm, with values between 0.150 and 1.994, and a mean value of 1.089. Evenness varied between 0.216 and 0.994, with a mean value of 0.737. No correlation between Shannon diversity index or evenness and farm size or total number of trees on the farm was found showing no difference between small and large farms in terms of diversity or evenness. In addition, there is no significant correlation between farm size and species richness (number of different species).

It is important to keep in mind that in general, frequencies of trees are not corresponding to occurrence on farms, as seen in the occurrence and frequency graph (Figure 5). This shows that some trees, such as avocado, are present on large number of farms, but there are only few individuals per farm, while grevillea has both high occurrence and frequency.

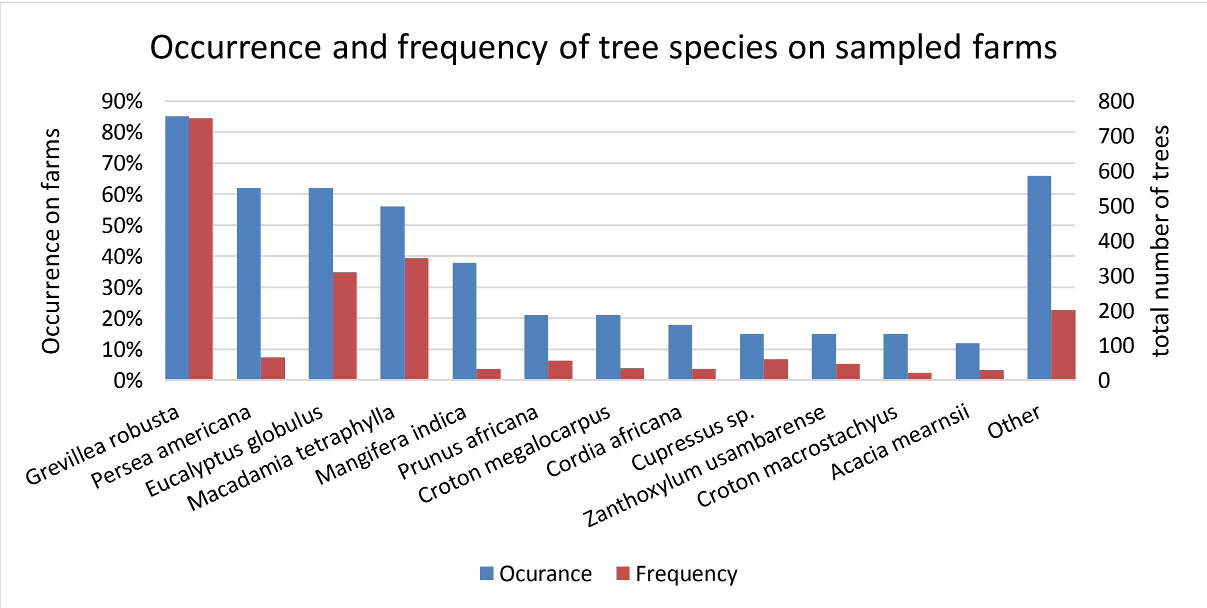

Figure 5 Occurance and frequency of tree species on sampled farms. Total numberof trees on Y axis represents total number on all sampled farms combined.

By frequency and occurrence on farms, the exotic species are dominant, but regarding the presence, there are equally many indigenous tree species as exotic (Table 5 in Appendix VI). Of the total number of trees listed by FGD roughly half the amount of species present on farms are indigenous (57 %, 11 of 19 tree species). Likewise, in SSI and questionnaires 50% of 24 identified species were indigenous.

As trees planting are closely connected to crops and livestock, to fully understand influencing factors and subsequent effects of trees, one must also understand the whole agroforestry system.

Crops and livestock

Main crops by occurrence on the sampled farms are presented in figure 6. The dominant crops are maize and beans, usually intercropped, used for both food and feed and with surplus often being sold. Banana is not a major source of income, but was identified as important for food security, especially if other crops fail as one of the interviewees explained. Many farmers (67%) have coffee, exclusively grown as a cash crop, illustrating the importance of cash crops. It is interesting that only two farmers used fodder trees. Napier grass is very common, important livestock feed in the area and 9 out of 9 farmers interviewed on farm had napier grass. Based on farms visited, the majority of farms have a cow and a calf, or two cows, some have goats and chicken are also common usually stall fed based on napier grass, supplemented by tree leaves, banana leaves, and maize stalks. Discovered in the FGD and supported by one large farm (4ha) having substantially more livestock, land availability is limiting the livestock production with farmers stating land shortage is limiting the capacity for increasing the amount of livestock. It is not uncommon for farms not to have any livestock.

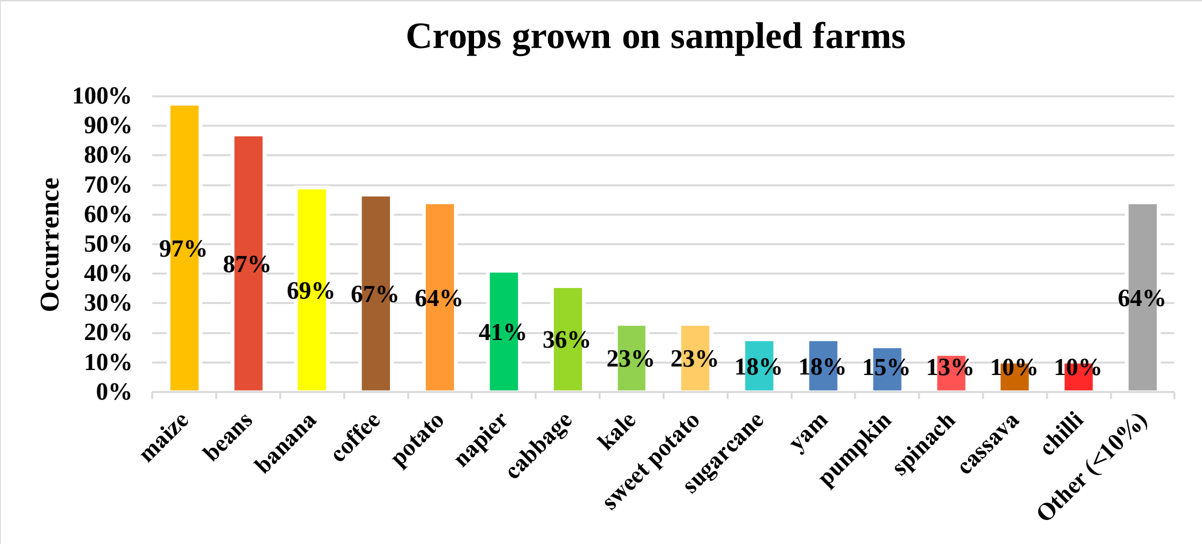

Figure 6 Crops grown on the sampled farms by occurance on farms.

Most of the farms (47%) sampled are reported as moderately steep, 13% being very steep. Possibly related to that, soil erosion and fertility were reported as problems by 18% of the farms (Figure 7). Stated by the participants of FGD the problem of decreasing soil fertility is linked to the land shortage. This is limiting the capacity for increasing livestock which causes limited manure to fertilize the soil. Surprisingly, trees were not found to be specified for their use in erosion control. Our observation on farms confirmed the lack of trees being planted with purpose of erosion control.

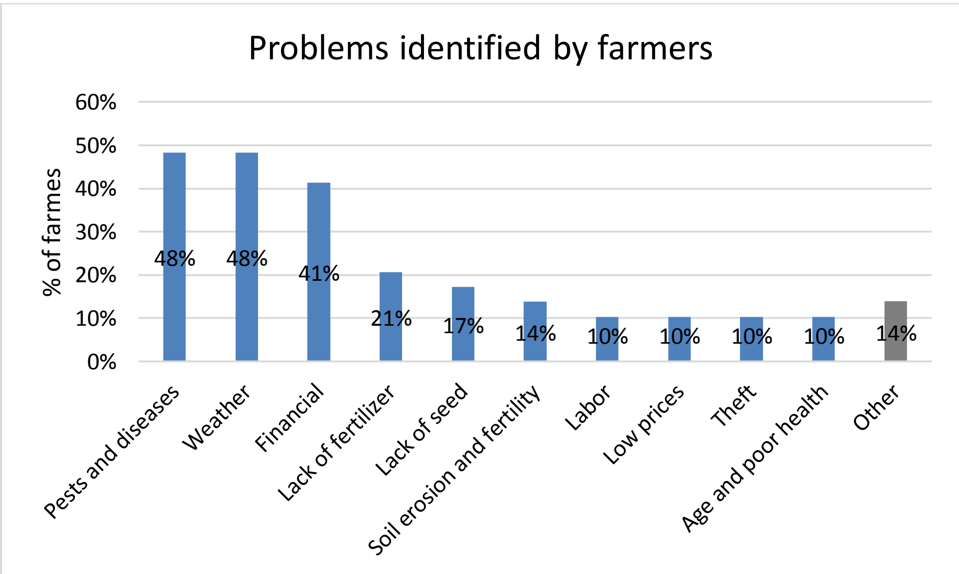

Figure 7 Problems in farming as reported by farmers.

Reasons for practicing agroforestry

Farmers practice agroforestry for several reasons. Economic outcome and contribution to self-sufficiency are main determining factors, while the underlying cultural reasons, perception of trees and perceptions of ecological effects also affect the agroforestry practices.

Perceptions and value of trees

The prominent use of exotic trees are rooted in farmers perceptions of the value of trees. This varied between respondents and appeared to be shifting. The theme emerged that a "good tree" is fast growing and usable for timber and fuelwood related to economic value. Trees meeting these requirements are typically exotic, with most favoring grevillea followed by eucalyptus (Table 2). However, some find eucalyptus to be a problem species. Four of nine farmers interviewed (45%), and all in the FGD consider Eucalyptus to be problematic due to negative association with crops. The conflicting opinions about Eucalyptus may reflect the shifting perception about the species in the study area. Other trees were identified as troublesome based on slow growth rate (*Prunus africana*) or limited use e.g. not good for timber (*Croton macrostachyus*, *Prunus africana*), or not useful for fuelwood due to thorns (*Erythrina abyssinica)*. Indigenous tree species were more often appeared under the context of problematic then under the prefered.

Table 2 Superior tree species (best trees) as identified by farmers with reported reasons and percentage of farmers. Origin of species is also shown.

Tree Species	E/I	Best Tree	Reason
Grevillea robusta	Exotic	63%	Fuelwood (31%), Soil fertility (26%), Timber (26%), Fast growth (9%), Intercropping (6%), Income (3%)
Eucalyptus spp.	Exotic	17%	Timber (43%), fuelwood (29%), Income (29%)
Macadamia tetraphylla	Exotic	13%	Income (100%)
Mangifera indica	Exotic	8%	Income (67%), Fruit (33%)
Persea americana	Exotic	4%	Income (100%)
Terminalia brownii	Exotic	4%	Fruit (100%)
Cordia africana	Indigenous	4%	Shade (50%), Soil fertility (50%)

Self-sufficiency and income

The economic effect of having trees can be identified as one of the main reasons for farmers to practice agroforestry. Financial problems (lack of money for labor, pesticides, fertilizer and farm intensification) are expressed as the main problem for farms in general and farmers aim for self-sufficiency, none of the problems being related to trees. Though no farmers directly mention trees as contributing positively to their financial situation this can be deduced from data. As identified in the questionnaires, SSI, and FGD, timber, fuelwood, and income from sale of fruits are the main purposes of trees grown on farms with top five trees having income as a purpose (Table 1). All the interviewed farmers use trees on their farm for fuelwood and timber, 7/9 being self-sufficient on these tree products. The two farms which are not self-sufficient on timber differ from the other farms by having less grevillea trees (< 20) and by not having many other trees for timber and fuelwood. One of the farmers stated that he could be self-sufficient if he had additional 0.8ha land to present 0.3ha, but to fully understand the reasons further study is needed.

Besides serving household needs, some trees function as a direct source of income for the household. Surplus timber production can be an important part of the income, with prices differing from 2,000 to 10,000 Kenyan Shillings per Grevillea tree.

Also income from fruits and nuts is important, as seen on in the Table 1 and Figure 8, and also supported by FGD participants as one of the main purposes of trees. Macadamia production is widespread in the area. All the interviewed farmers either sell macadamia nuts or have planted macadamia with future sale in mind. Due to the profitability of trees and the general problem of lack of capital, theft of macadamia seedlings is problematic in the area (10% of questionnaire respondents and validated by one key informant. Despite these findings, seed and seedling access or cost are not identified as a problem.

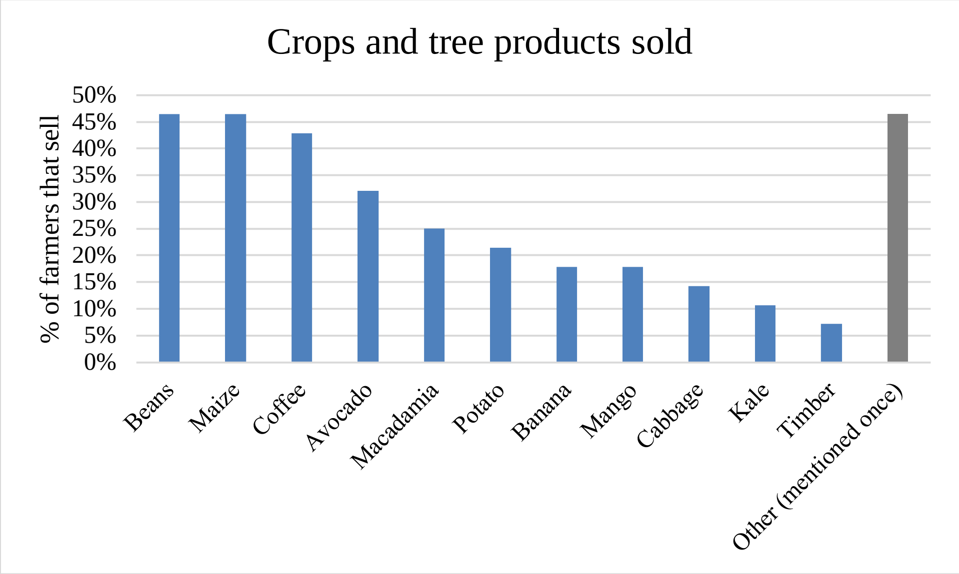

Figure 8 Percentage of farmers that report to sell certain crops and tree products.

Ecological values and perceptions of trees

Regarding ecological effects, in general farmers in the area reported perception of trees in terms of tree-crop interactions, support to crops, shading effect, effect on soil, and microclimatic environment trees provide in the farm.

A variety of practices regarding mixing trees and crops exist. *Grevillea robusta* are intercropped with maize and coffee in 74% of the respondents' farms (Table 1), the most frequent reason voiced being it not interfering with crops. Three interviews also added that leaf fall increases the soil fertility by adding organic matter. *Grevillea robusta* leaves were commonly used for mulching the coffee and composted with animal excreta. As mentioned by an interviewee, grevillea leaves were also being used for the bedding for cows and later composted with manure. Besides Grevillea, avocado and macadamia were mentioned once for the same purpose.

According to farmers perceptions *Eucalyptus globulus* and *Cupressus* sp. were found to be harmful to the crops and soil. Three interviewees responded that Eucalyptus consumes too much water resulting in dry soil on the farm. However, Eucalyptus is considered important for income due to timber and fuelwood production despite knowledge that intercropping is not possible. Most of the farmers are growing eucalyptus in woodlots (50%) and on boundaries (21%) preventing close contact with crops. *Cupressus* sp. was considered harmful as the growth of the crops nearby is inhibited by lateral roots growing above ground as mentioned by an interviewee.

Knowledge of nitrogen fixation by leguminous trees present on farms seems unknown to the farmers. Trees such as *Albizia gummifera*, *Erythrina abyssinica* were mentioned in FGD, interviews and questionnaires in a few farms but no one mentioned N fixation or soil benefits.

Shading

Grevillea robusta, Macadamia tetraphylla, Cordia Africana and *Euclea divinorum* are found to be grown for shade (Table 1 and Appendix II). However, only 13% of the all farms sampled by SSI and questionnaires use trees for shading and it was voiced by interviewees that excessive shading causes stunted growth and lower productivity of crops. One key informant stated nothing grows under the Macadamia with leaves hardly decomposing supported by field observations from a Macadamia plots. Pruning of branches of trees are common practice in avoiding too much shade on the crops during planting and flowering season, besides pruning for fuelwood. In the responses from FGD and questionnaires it was not clear whether the shade is for crops or for people. Three farms interviewed keep trees for shade to coffee and no interviewee mentioned shade for people, but based on our observation of the farms as the trees were around the household shade for people is also valuable.

Factual ecological effects of agroforestry

The perceptions on the effects mentioned above can contrast from the actual effects. In general, people have some knowledge on the environmental benefit of trees but lack knowledge on the mechanisms seen from statements such as as “the trees promote rain,” “clean the air,” “provide shading,” and “control winds”.

Microclimate effects

Field measurements of temperature show a reduction of daily maximum temperatures in maize-grevillea mixed system by approximately 3°C compared to sole maize. In woodlots, the reduction was even greater (6-7°C) (Figure 9). Interesting result is that after 19:00, when the air starts to cool down, the temperature in woodlot drops at slower rate, some time even being higher than in other systems, the woodlot decreasing the daily temperature amplitude. As it can be expected, relative humidity trends were opposite of those of temperature (Appendix VII).

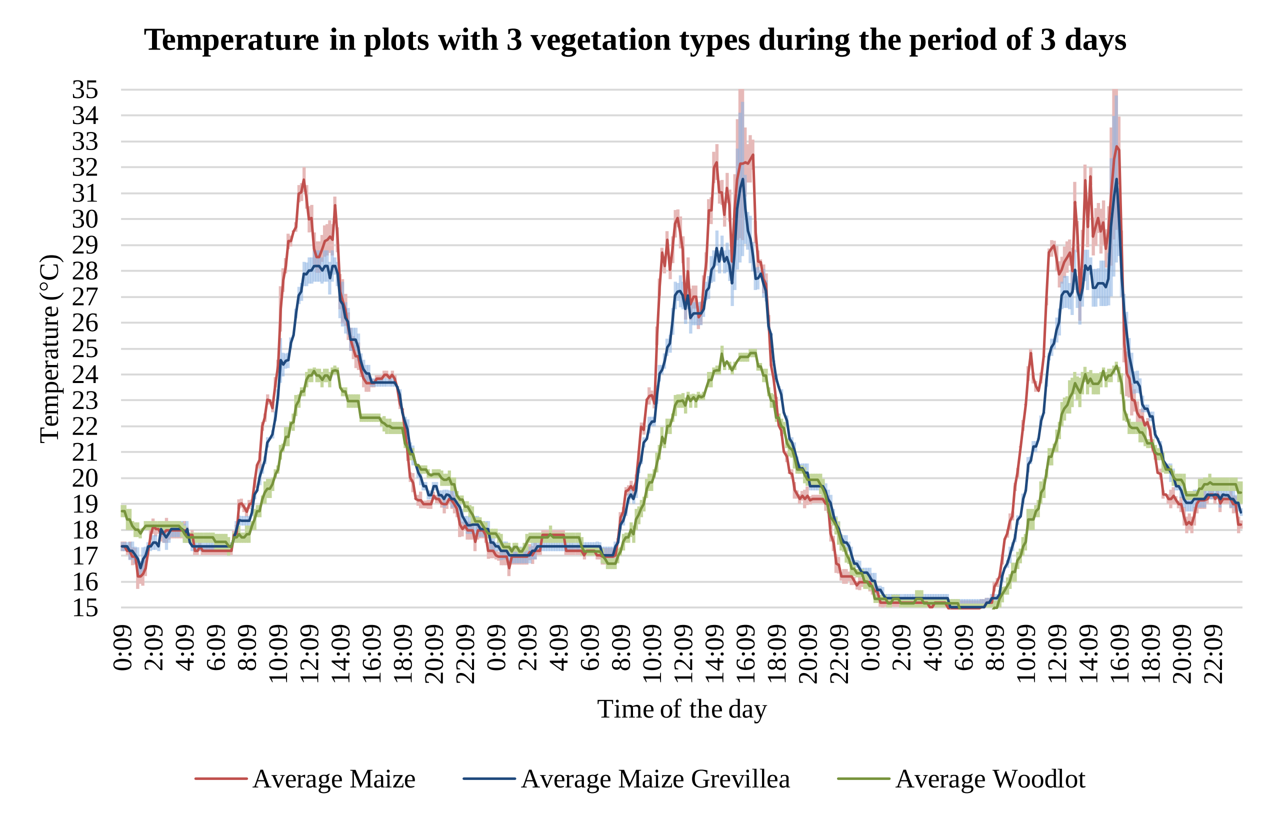

Figure 9 Temperature variations in 3 different vegetation types during the period of 72 hours. The light colored area around the lines represents standard error of the mean.

Effects on soil

The plots are not largely different regarding texture and laboratory analysis and are regarded as comparable. When investigating pH, soil content of N and C, and bulk density, no general trends for all farms were identified between three investigated systems.

Texture

The texture of the plots are mainly silt loam, with two farms being more clayey (Table 6 in Appendix VIII). There were not distinct differences on the three sites on the farms except at farm 2 with the woodlot being more silty. When making profiles, shiny surfaces (Figure 27 in Appendix VIII) were discovered at 60 cm depth at the maize and maize grevillea plots, and at 40 cm in the woodlot which could be an indicator of a nitic horizon. The iron content and the textural diagnostic criteria have not been confirmed in the laboratory but field identification are corresponding well to the FAO field description of a Nitisol with our soil having a texture class of silt loam, no abrupt color difference in the horizons and apparent shiny surfaces.

The bulk density of the plots range between 0.81 g/cm3 and 1.03 g/cm3 with all farms but one having values below 0.9 g/cm3 (Figure 21 in Appendix VIII). The higher bulk density of one farm (farm 2) aligns with this having a more clayey structure (Figure 21 in Appendix VIII). . The bulk density found in this study corresponds to findings of Kenyan Nitisols by Kapkiyai et al. (1999) having mean values of 1.1 g/cm3 and Agegnehu, Nelson & Bird (2016) finding bulk densities at 0.98 and 1.02 for Nitisols.

Carbon and nitrogen content

For both total C and total N content and permanganate oxidizable carbon (MnoxC), there were no general significant trends between the farms, though some significant differences within farms appear (Figure 10 and 11, and Figure 20 in Appendix VIII). Differences between the three investigated systems are identified when comparing the A and B-horizons from farm 1. The woodlot have the same amount of C and N in the A and B-horizon, whereas the sole crop and mixed system have more C and N in the A-horizon, these numbers also higher than for the woodlot. In the B-horizon, the C and N content are higher for the woodlot than the sole crop and mixed systems (Figure 10 and 11).

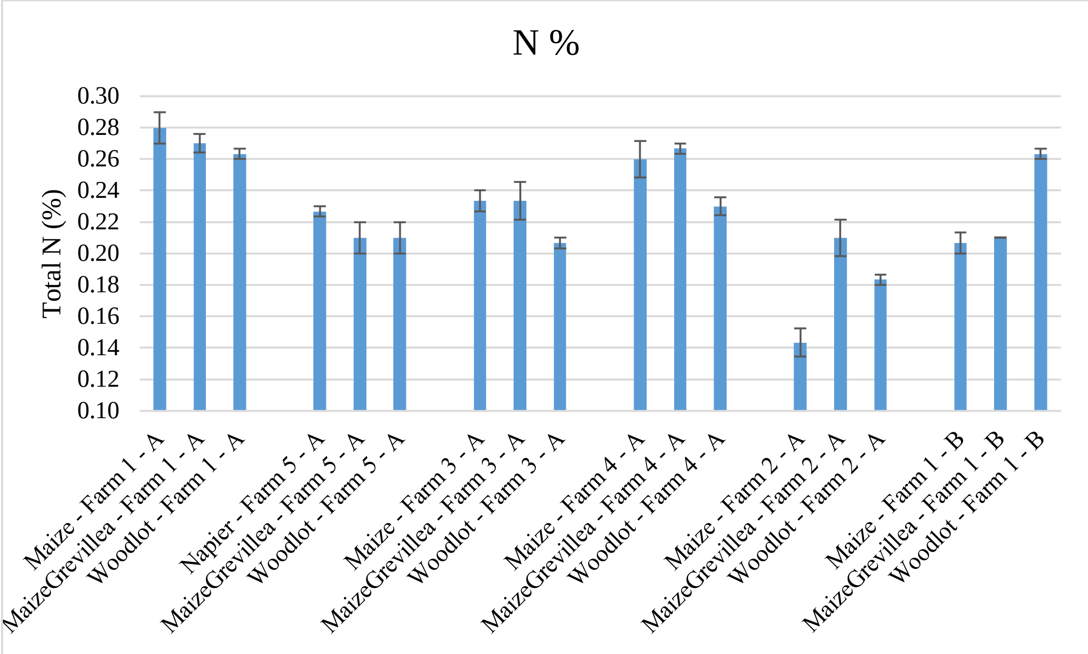

Figure 10 Total nitrogen in the soil by percentage. A represents A-horizon and B, B-horizon of the soil.

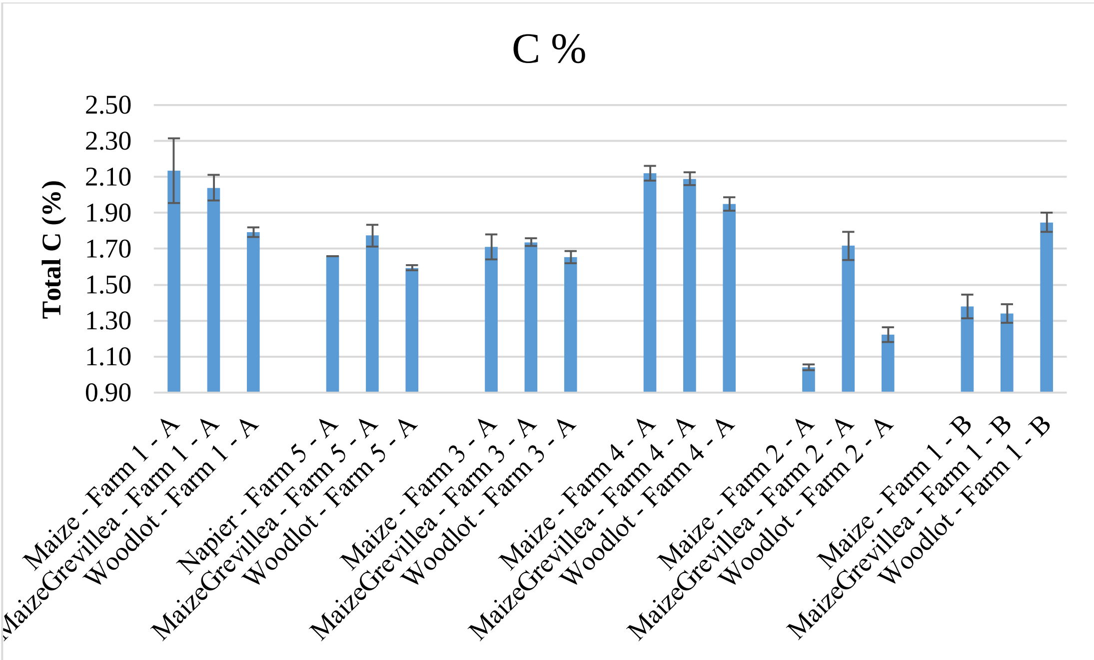

Figure 11 Total carbon in the soil by percentage. A represents A-horizon and B, B-horizon of the soil.

The C:N ratio of the soils are between 6.5 and 8.6 (Figure 25 in Appendix VIII) with with N % values ranging from 0.14 % to 0.28 % and C % ranging from 1.04 % to 2.13 %, both from maize sites. The C:N ratio of the soils fits with the study area with the tropical environment facilitating large rates of decomposition due to temperature and humidity and C:N < 25 in general facilitate mineralization of plant-available N (Brady and Weil 2013). The C:N ratio decreases with decomposition due to relative increase in N content due to C loss from respiration (Brady and Weil 2013). It must be noted that the C and N calculated by dry combustion method are the total C and N, and does not represent amounts directly available to plants. A trend can be identified with the lowest C % is in the horizon with the largest bulk density and the highest values of C % corresponding to the lowest bulk densities (Figure 21 in Appendix VIII), implying a connection between carbon content and bulk density.

pH

Overall, the pH does not vary much between farms, with values between 5 and 6 (figure 12). For three out of four farms (Farm 1, 2 and 3) with sole crop and tree-crop mixed systems, there is a significantly higher pH in the mixed plots compared to sole crop plots. In the woodlots, the pH is higher compared to sole crop at two farms with woodlots composed primarily of grevillea (Farm 1 and 3). For farm 1 with both A and B-horizons under study, same difference is seen in both horizons. In farm 2 there was no significant difference in pH between sole crop and woodlot, possibly due to the woodlot mostly consisting of trees other than grevillea.

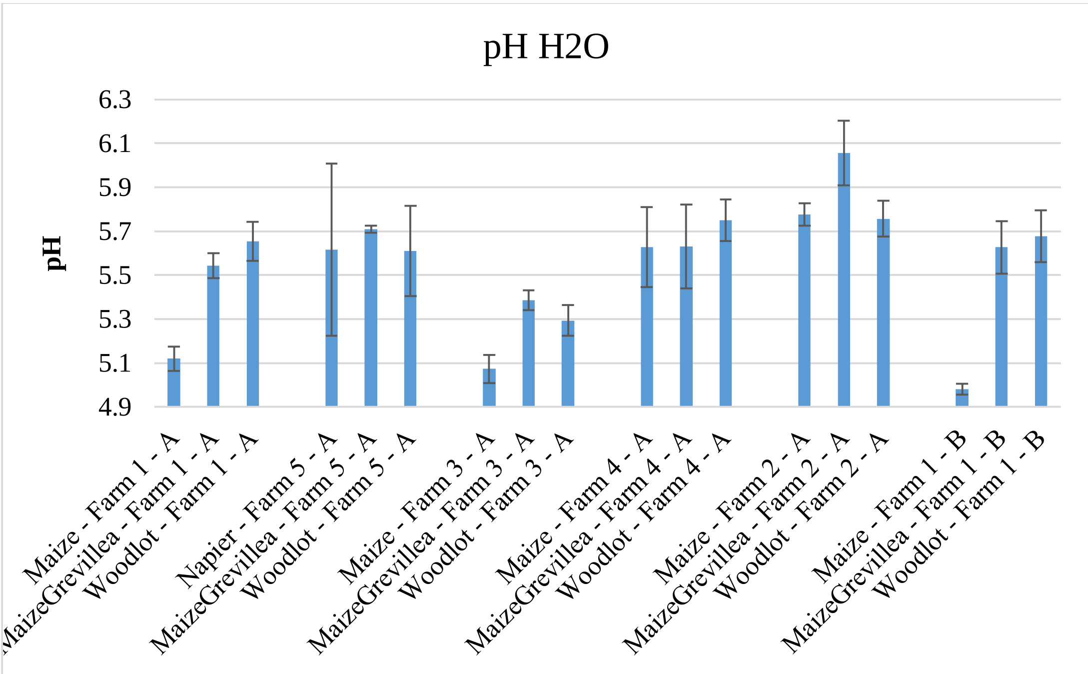

Figure 12 pH of the sampled soils as measured in H2O. A represents A-horizon and B, B-horizon of the soil.

Cultural importance of agroforestry

Sociocultural factors and effects of agroforestry include the value and perception of trees, the cultural significance of certain trees, conventional wisdom related to tree planting, and support systems for agroforestry.

Culture of Trees and Tree Planting

There is a clear culture of tree planting in the study area, appearing to be a recent development, mentioned in interviews and by informants and as described by a key informant:

> *"Many people have started planting trees as of late, since 1970. After Mau Mau. Before, people were not planting trees because there was no land ownership. After independence there was land ownership and people started investing in their land with trees."* Phillip Kibanga

Some farmers stated they did not have trees previously, which we confirmed by analyzing the historical satellite imagery by comparing the presence of trees on farms in images from the year 2003 and 2014 (figure 13).

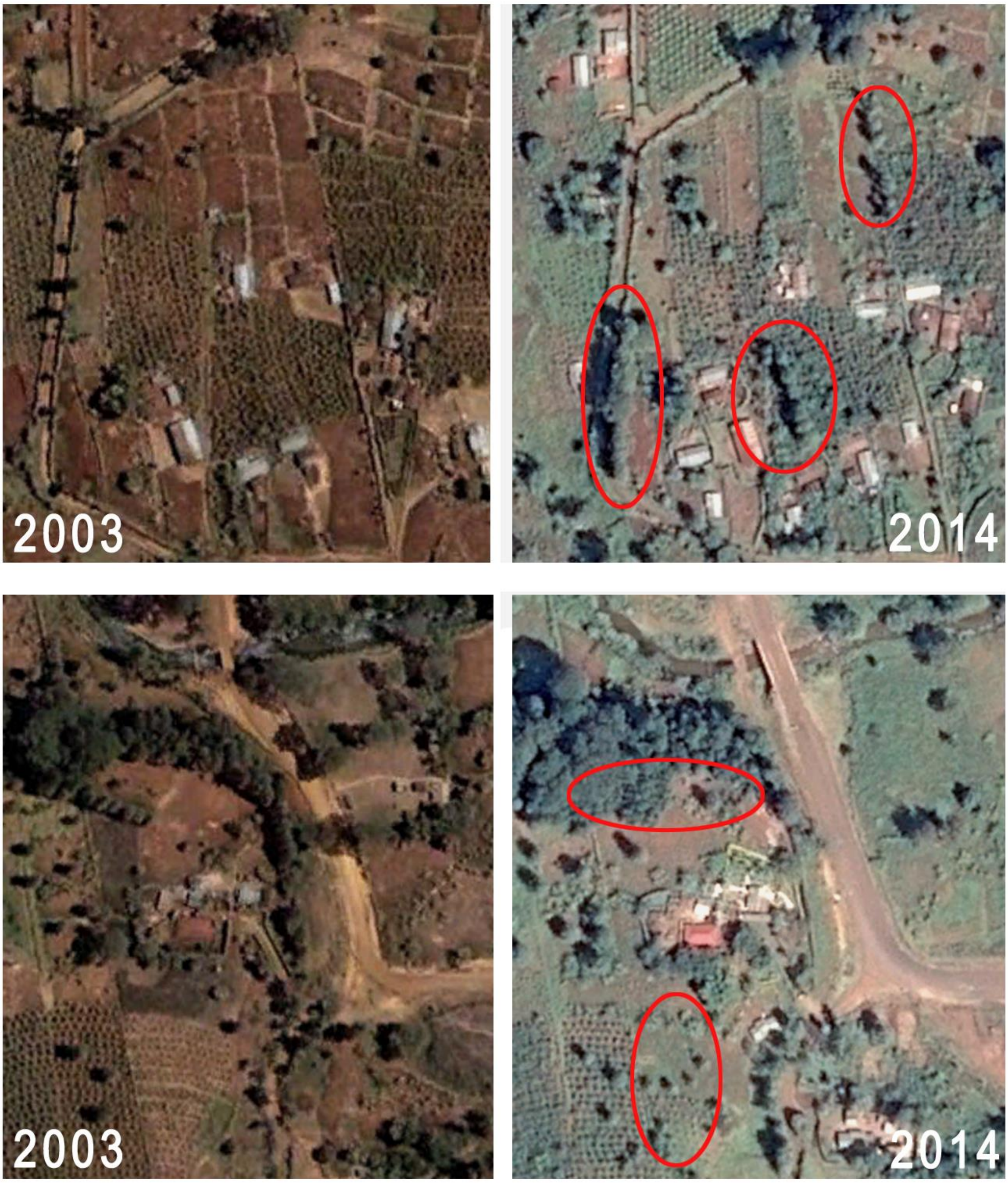

Figure 13 Satellite images examplifying the change of tree densities in the Gakina area between 2003 and 2014 on thwo of the visited and interviewd farms. Source: Google Earth, 2016

Several common practices, which seemed to reflect traditional knowledge, were identified The practice of "cut one, plant one" is described by key informant Lucy Waraguru Ndentu:

"People are cutting, and replacing [their trees], not only cutting. People know the benefits of trees".

Five of nine interviews (55%) reported managing their trees in this way. As reported in the FGD and two interviews, allowing naturally germinating trees to continue to grow is common even on very small farms, 0.2ha in one case. However this practice depends on the species of the tree. The practice of planting trees along a boundary to demarcate different farms, is a common practice, and is described as "Kikuyu culture" in three interviews and by one key informant. According to interviewee Beatrice Wambui Waithaka.:

"I put them (Commiphora zimmermannii) on the boundary because my father did it that way. It is Kikuyu culture to use this tree on the boundary".

Although many indigenous trees are of low or no economic value to some farmers, they hold cultural, historical, and medicinal value to others. According to the FGD, two key informants, and two interviews, the indigenous trees *Cordia africana* and *Ficus thonningii* (wild fig) are associated with the Mau Mau uprising, said to be planted by the Mau Mau themselves or to have been used in their rituals. Although they are no longer worshipped, they are not permitted to be cut, or used for fuelwood or timber, but according to field observations this rule does not seem to be strictly followed. Two interviews identified other indigenous trees as having medicinal use.

Support structures for agroforestry

According to the focus group, two interviews and a key informant, prior to the death of its founder Wangari Maathai, the Green Belt Movement (GBM) was influential in the area, providing support for tree planting in the form of tree nursery contracts, and training on tree planting. However since 2011, direct support from GBM in the area has ceased. The recently established community organization, W Power, aiming to create tree nurseries and provide training on sustainable fuelwood production is lesser known, not identified in questionnaires or interviews. According to one key informant and several interviews, participation in existing farmers groups, and community trainings is lacking. However, there is individual production of tree seedlings, and the presence of small tree nurseries on farms according to individual needs. Formal support for tree planting or agroforestry does not appear to be a perceived need on behalf of the community, except for the minority of respondents (one key informant, and one interview), However, the legacy of GBM persists in the area, as demonstrated by the tradition of planting trees described above, also described by key informant Lucy Waraguru Ndentu:

"The knowledge of the importance of trees to the people are well known. For example, they cut branches instead of trees."

Discussion

Economic factors shape agroforestry systems

The trees chosen for agroforestry are mainly those contributing to household needs for direct income. Appiah & Pappinen (2010) and Castro (1991) also identify trees as playing a critical role in farmers' livelihood. Exotics which are fast growing, with income or self-sufficiency value are strongly preferred and much more abundant than indigenous species of any kind, as can be seen in the tree abundance table (Table 1). Also, Appiah & Pappinen (2010) identified that exotic species are preferred by farmers due to their ability to provide short-term cash income, fuel, and shade. Environmental benefits or other purposes (e.g. for fodder) are of secondary importance.

The literature suggests that financial problems can be a constraint for agroforestry (Appiah & Pappinen 2010). However our study did not identify limited capital as a barrier to having trees on farms. Instead, economic problems are affecting agroforestry indirectly. We found that small farms (<0.5ha) have significantly higher density of trees compared to larger farms which is consistent with previous studies that found the same trend in similar areas in Kenya (Reppin, 2014; Pinard et al. 2014). This illustrates the importance of having trees despite very limited land size. Furthermore, having more trees is a tradeoff between having more crops, so farmers must find a balance between the need for timber and fuelwood, and the need for crops, as also reported by Appiah & Pappinen (2010). As we discovered, the economic pressure did not result in fewer trees on small farms, but shaped the system. Concrete examples of such is the mixing trees and crops only when shade is desirable, controlling the amount of shade by pruning, controlling the density of trees, and planting eucalyptus on the boundary since it cannot be intercropped.

Limited capital is mentioned as main challenge among farmers, which explains the efforts to be self-sufficient as much as possible. The practice of agroforestry can contribute to general self-sufficiency and most of the farmers studied produce enough fuelwood, timber, and food crops for household needs, with many earning income from timber or crops (Appiah & Pappinen, 2010). The choice of tree species is directly related to self-sufficiency on the farm, and exotic species are heavily preferred for timber and fuelwood since they are usually fast-growing and therefore perceived as superior to indigenous species. Surprisingly, they do not use tree species that could contribute to self-sufficiency and diversification of fodder.

Culture and agroforestry

The culture of planting trees on Gakina farms is a common practice, and some farmers have more trees now than in the past as detected from satellite images and interviews (Figure 13). This is supported by Backes (2000), stating how examples from Kenya show significant increases in trees from the 1980s, especially on small farms, as population has increased.

However, the species composition changed greatly from traditional systems. The replacement of indigenous trees with exotics is showing a decrease in cultural importance, and a simultaneous increase in economic valuation of trees. We identified several factors that contributed to this trend of suppression of cultural values. Decreasing farm size and agricultural intensification are the main factors, since they lead to less space for non-income generating indigenous trees with cultural importance. The change in tree preferences, and low cultural valuation is exemplified by several farmers cutting and using e.g. *Cordia africana*, a tree that our respondents also associated with the Mau Mau uprising. Traditionally, trees played a vital role in religious practice, for medicinal use, and foods (Dewees, 1995), but changing preferences have led to some loss of awareness of the cultural legacy and significance of certain trees. For example, only one farmer studied indicated the medicinal use of trees.

We found that decreasing farm size did not affect the diversity and evenness parameters. Given that households are utilitarian in their management of trees, there must be a reason why farmers choose to keep trees that are less common and with less apparent use (Table 1) rather than remove it from small farms, given that having "less useful" trees is a tradeoff to having more crops, or more of the "useful" trees (Castro 1993). Similar findings of farmers retaining trees without specific purpose, where trees are not interfering with crops are mentioned by McNeely & Schroth, (2005). The complete explanation remains elusive in this study, yet could partly lie in cultural values. Some traditional uses and cultural practices have been found to still exist in the studied area. The best example is the culture of planting trees on the boundary. In pre-colonial times it was the accepted Kikuyu way to demarcate the boundaries, and is the result of customary land tenure practices (Dewees, 1995). The report from 1995 claims that the trees in the boundary are not grown for economic value, however, we discovered that it is not the case, which may indicate that due to decreasing farm size and economic pressure, trees on the boundary today also have economic value, mostly as timber and fuelwood source (Dewees, 1995). This shows that cultural and economic valuation of trees need not be mutually exclusive. It is interesting to say that most of the economically valuable trees on the boundary are exotic species. Dewees (1995) also reports that boundary demarcation with exotic trees gradually became the norm.

Planting trees has in recent times been promoted by GBM across Kenya, which may have contributed to farmers perceptions. However, even though the general perceptions and awareness about tree planting remained, changes did happen after the founder of GBM, Wangari Maathai, passed away. According to our findings, since her death, local people no longer receive economic benefits from having large tree nurseries, which resulted in no commercial nurseries, as observed in the field and confirmed by farmers. This again supports previously discussed finding that economic aspects are the dominant factor in decision making in agroforestry.

Informants and guides mentioned that fig trees do not produce fruits, but they still have a religious, cultural and ecological value, and are considered sacred, aligning with the literature (Leakey 2013; Dewees 1995). However, we only identified one farmer that has a fig tree on their farm, and it was a single tree.

Changing farm sizes and agricultural intensification

The decreasing farm size is a major factor contributing to the overall look of the system and the decision making within. Literature supports our hypothesis and finding, showing a clear trend of decreasing farm size from one generation to the next via inheritance (Shreffler and Nii-Amoo Dodoo 2009). A study done at multiple locations in Kenya shows that decreasing farm size results in overutilization of land and decline in agricultural productivity, increasing the need for inputs (Shreffler and Nii-Amoo Dodoo 2009). In addition, our finding that land shortage limits capacity for more livestock and therefore limits the availability of manure, suggests possible decrease in soil fertility. In combination with decreasing farm size, decreased area per person on smaller farms means that production must be intensified. This trend is likely to continue, at least on bigger farms, since we found that the area per person on those farms is still not as low as on small farms. Even though we did not find evidence of decreased diversity on small farms, if the trend of preferring exotic species with high economic value continues, there is a danger that indigenous species may be displaced. The mean evenness value of 0.7 in our study, combined with the higher abundance of exotic trees found, shows a lower proportion of indigenous to exotic species on farms. This corresponds to the findings of Pinard et al. (2014) in coffee agroforestry systems, where it was concluded that these systems are not likely to serve as reservoirs for indigenous trees. A major reason for discussing the observed changes in exotic and indigenous trees are looking into values of preserving indigenous trees in agroforestry systems. Keeping indigenous trees can contribute to biodiversity, enhancing the resilience of the farming system, as it can provide important pest control agents, seed dispersers and pollinators with diversity of genes, species and ecological processes being important for ecosystem services (Fischer, Lindenmayer & Manning, 2006).

Multipurpose Trees

Most trees present on smallholder farms are for fuelwood and timber, or for another singular use such as fruits or nuts. With the exception of grevillea, there are very few trees with auxiliary benefits to fuelwood, timber, or fruits were present. The potential in the area however exists, as documented in the literature and illustrated in Table 3, showing multipurpose trees with uses and benefits in Kenya (Ariga 2008, Appiah & Pappinen 2010, Castro 1993).

Table 3 Potential multipurpose trees and their potential uses and services. Adapted from World Agroforestry Center Database, 2009

Tree Species	Known uses											Exotic or Indigenous
	Food	Fodder	Timber	Fuelwood	intercropping	Boundary/ Support	Erosion Control	Shade/ Shelter	Nitrogen Fixing	Soil improvement	Medicine	
Albizia gummifera			x	x			x	x	x	x	x	Indigenous
Calliandra calothyrsus		x		x	x	x	x	x	x	x		Exotic
Erythrina abyssinica		x			x	x	x	x	x	x	x	Indigenous
Leucaena leucocephala	x	x	x	x			x	x	x	x		Exotic
Moringa oleifera	x	x	x	x	x	x	x			x	x	Exotic
Sesbania sesban	x	x		x	x	x		x		x	x	Indigenous
Tephrosia emeroides						x		x	x	x	x	Indigenous

The most used fodder on all investigated farms is napier grass, while fodder trees were identified only at two farms. For example, calliandra was used by only 5% of sample population in low numbers, where it was used for fodder or mulch. The indigenous nitrogen-fixing trees (A. gummifera, and E. abyssinica) were more often present, but were not valued for soil benefits. Erythrina was even once identified as useless, problematic tree. This indicates that integration of trees in the crop-livestock system is not optimal. Intercropping experiments with napier and calliandra performed near our study area shows no decrease in napier yield, illustrating the potential of such intercrop (Franzel & Kiptot, 2014). Also, according to literature, most fodder trees can provide other services such as timber, fruit, soil cover or improvement of soil fertility. However, most fodder trees are knowledge-intensive, and implementation requires that farmers acquire some skills regarding seed collection, nursery establishment and pruning and other management practices (Franzel & Kiptot, 2014).

The lack of fodder trees and multipurpose trees in general in this study area can be argued to reflect the weak extension support in the area. Supporting that, we found that farmers are learning about trees benefits from agricultural extension officers, but on the other hand, substantial amount of farmers are not in contact with agricultural extension, limiting the flow of information.

Another factor favoring the use of grevillea and limiting the use of other multipurpose trees is certainly the fast rate of growth of grevillea. We were unable to prove or disprove influence of factors such as the availability of planting material, knowledge availability, or cultural reasons. However, given the expressed problems of soil fertility, lack of manure and fertilizers, and also considering the potential of un-utilized tree species, low awareness is likely another factor.

Perceived and actual ecological effects

As identified in field, and reported in literature, even when perceptions do not have factual basis, they can still play critical role in decision making (Mejier et al. 2015). This is illustrated with the farmers practices in connection to practies. The farmers perceptions of ecological effects are to some extend determining for their tree management. When comparing with literature and actual ecological effects on microclimate and soil, it can be identified that some of the farmers perceptions have factual basis, while others are based on misconceptions. Literature suggests that grevillea can serve as a buffer for climate extremes by reducing transpiration rates due to shade (Lott, Ong, and Black 2009). Shade from the trees reduces solar radiation that reaches the area below. In addition, tree canopy absorbs part of the the incoming solar radiation which is used for heating the leaves and evaporation. Thereby less energy heats the air, reducing the temperature (Bonan, 2015). These effects of trees were confirmed by our microclimate measurements with substantial reduction of day temperatures resulting in smaller daily temperature amplitude.

Related to the discussion on farmers having to find a balance between crops and trees on small farms to get both enough food crops and timber, farmers intercrop grevillea because they can prune it so it does not affect crops. This is in line with the literature reporting increased light availability to crops when grevillea is pruned (Lott, Ong, and Black 2009). When comparing to literature, the tree densities that we observed is found not to have negative effect on crop yields, while higher densities are found to be negative (Muchiri et al. 2002; Lott et al. 2000; Ong et al. 2000). Farmers seem to have found the optimal balance between trees and crops through experience, since they perceive that in higher densities shade is limiting factor, as opposed to water competition as reported in literature (Lott et al. 2000; Ong et al. 2000).

Farmers perceive grevillea as being neutral towards crops and application of grevillea mulch and compost is common in the area, and farmers claim the positive effect on soil fertility. When analyzing results no general trends between the three investigated systems were identified. The C and N content were not significantly higher with Grevillea or in woodlots compared to sole crop plots. The woodlots investigated were young, which could be a possible explanation for the lack of effects of the trees on the soil. The lack of general trends could also be due to the heterogeneous nature of the soils. Differences in C and N content in the three investigated systems can be recognized by looking at differences on Philips farm between the three systems A and B-horizons.The higher percentage of C and N in the A-horizon of sole crop and mixed systems (Figure 10 and Figure 11) can be due to farm practices such as intercropping of nitrogen-fixing beans, fertilizer and manure applications, and hoeing in the upper 20 cm. Oppositely, in the B-horizon the percentages of N and C are higher in the woodlot than the sole crop and mixed systems, indicating that trees contribute to subsoil carbon. Another explanation could be the removal of the nutrients in the sole crop and mixed plots at 60 cm depth.

The literature contradicts grevillea being a tree without negative effects as farmers perceive. Yobterik et al. (1994) demonstrated that such mulching suppress growth of maize due to toxicity of excess Manganese. Furthermore, it can induce nitrogen immobilization in the soil due to slow release of N (Yobterik, Timmer, and Gordon 1994). In addition, the study suggests that grevillea mulch increases the pH of the soil (Yobterik, Timmer, and Gordon 1994). As seen in results from our measurements, the pH of the sites with Grevillea are found to be significantly higher than the sole crop plots, aligning with the reported claims.

On the other hand, mulching has positive effect on soil and water run-off (Omoro and Nair 1993). This illustrates the multifaceted discussion on which farm practices to prefer.

The discussion on economical values dominating farmers tree choice can be illustrated by farmers perception and use of eucalyptus. Farmers mention negative effects of eucalyptus on water consumption and inability to be intercropped, but since it is perceived as one of the faster sources of fuelwood, it is widely grown in woodlots and on boundaries. The literature (Addis 2009) agrees that Eucalyptus provides fast biomass at the expense of heavy water consumption with the effects on crops being pronounced to around 10m from the tree. The litter is discovered to have allelopathic effects, especially when soil is dry. Its contribution to soil organic matter is described as questionable. Negative effects of eucalyptus on soil quality can be seen in the long term if harvesting cycle is short as there is not enough time for nutrient levels to recover (Addis 2009). This may be a problem in areas such as Gakina where, due to limited land availability, farmers are forced to intensify the production.

Conclusions

Agroforestry is the definitive farming system in Gakina. The practice has a historical basis, but in the years following independence, with property rights, it has become ubiquitous and trees are a means of investing in land. In recent years, agroforestry has been intensified from previous generations. This is surprising considering the simultaneous trend of decreasing farm size, and is evidence that trees have significant value to smallholder livelihoods.

Land fragmentation is indeed taking place in the study area. There was no instance of land increase between generations, with most farms decreasing in size drastically with each generational transfer. Land fragmentation, as well as economic considerations, are the main factors shaping agroforestry systems, affecting the choice of trees, pruning regimes, density, and configuration.

Agroforestry systems are not easily categorized. Rather than a clear typology of boundary, woodlot, and mixed systems, there is a variety of configurations, combining these three types, and adding new complexity to the system. Farmers adapt tree density and configuration based on a variety of factors such as the compatibility of trees with crops, the need for wood, and the occurrence of tree seedling volunteers.

Economically-driven preferences for trees have resulted in the most common trees on farm being exotic wood and fruit trees. These exotic species are replacing indigenous species, which today are much less common in occurrence and number. Indigenous species remain present nonetheless, which may be due to their enduring cultural value, or perhaps they are simply relics of the past. Economic importance is trumping cultural importance, although they aren’t necessarily mutually exclusive. Spiritual, historical, and medicinal value is not as important as it once was, and so the cultural legacy of trees is both physically and ideologically being lost.

Remarkably, the effect of the utilitarian attitude about trees has resulted in self-sufficiency in fuelwood and timber on most farms surveyed, despite the very small size of many of these farms. Relatively few species are used, usually with only one or two uses. However, there are additional options, such as multipurpose trees. They include many indigenous species, and could both diversify farm products, contribute to soil fertility, maximize land use efficiency, and also contribute to agrobiodiversity.

For most, the trees on the farm have mostly negative effects, but the farmers very often perceive them as having a positive effect. Ecological interactions of trees and crops, and other ecological effects of trees have limited understanding among farmers. With better understanding of tree effects on intraspecies interactions, climate, soil and water use, it could be expected that the system would be more productive and resilient. In addition to contributing to self-sufficiency, trees could help mitigate problems of unpredictable rain, declining soil fertility, limited land size, and would also contribute to the increase of livelihood opportunities. One of the reasons for perceptions that differ from reality is a weak link to agricultural extension. In addition, low participation in farmer groups limits the spread of information.

References

Addis, Ababa. 2009 “Eucalyptus in East Africa The Socio-Economic and Environmental Issues.” FAO Sub-regional Office Eastern Africa.
Agegnehu, Getachew, Paul N. Nelson, and Michael I. Bird. 2016. “Crop Yield, Plant Nutrient Uptake and Soil Physicochemical Properties under Organic Soil Amendments and Nitrogen Fertilization on Nitisols.” *Soil and Tillage Research* 160 (July): 1–13. doi:10.1016/j.still.2016.02.003.

Appiah, Mark, and Ari Pappinen. 2010. “Farm Forestry Prospects Among Some Local Communities in Rachuonyo District, Kenya.” *Small-Scale Forestry* 9 (3): 297–316.

Ariga, Emmanuel Safary. 1997. “Availability and Role of Multipurpose Trees and Shrubs in Sustainable Agriculture in Kenya.” *Journal of Sustainable Agriculture* 10 (2-3): 25–35. doi:10.1300/J064v10n02_05.
doi:10.1007/s11842-010-9117-z.

Backes, Martina M. 2001. “The Role of Indigenous Trees for the Conservation of Biocultural Diversity in Traditional Agroforestry Land Use Systems: The Bungoma Case Study: In-Situ Conservation of Indigenous Tree Species.” *Agroforestry Systems* 52 (2): 119–32.

Bonan, G. 2015. *Ecological Climatology*. Second Edition, 8th printing. United Kingdom: Cambrigde University Press.

Brady, Nyle C, and Raymond Weil. 2013. *Nature and Properties of Soils, The: Pearson New International Edition*. Pearson Higher Ed.

Castro, Alfonso Peter. 1991. “Indigenous Kikuyu Agroforestry: A Case Study of Kirinyaga, Kenya.” *Human Ecology* 19 (1): 1–18.

Castro, Alfonso Peter. 1993. “Kikuyu Agroforestry: An Historical Analysis.” *Agriculture, Ecosystems & Environment* 46 (1): 45–54.

Christiansson, Carl. 1988. *Geographical Studies in Highland Kenya 1987-1988, Report from Geographical Field Courses in Endarasha and Othaya, Nyeri District, April-May 1987 and April-May 1988*. Kulturgeografiskt Seminarium <<1/88=88,1>>. Department of Physical and Human Geography, University of Stockholm.

Dewees, Peter A. 1995. “Trees and Farm Boundaries: Farm Forestry, Land Tenure and Reform in Kenya.” *Africa: Journal of the International African Institute* 65 (2): 217–35. doi:10.2307/1161191.

Dharani, Najma. 2002. *Field Guide to Common Trees & Shrubs of East Africa*. Struik.

FAO. 1997. *FAO/Unesco Soil Map of the World*. ISRIC, Wageningen.
FAO 2006: Guidelines for Soil Description. 2006. 4th ed. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2016. “Agroecological Zones of Kenya. Cropping Calendar.” FAO.

Franzel, Steven, Sammy Carsan, Ben Lukuyu, Judith Sinja, and Charles Wambugu. 2014. “Fodder Trees for Improving Livestock Productivity and Smallholder Livelihoods in Africa.” *Current Opinion in Environmental Sustainability* 6 (February): 98–103. doi:10.1016/j.cosust.2013.11.008.

(Garmin, 2016):
https://buy.garmin.com/en-US/US/into-sports/discontinued/gpsmap-62s/prod63801.html
Visited last 7.4.2016

GBM (2016). http://www.greenbeltmovement.org/who-we-are/our-history
Visited last 7.4.2016

Google Earth V7.1.5.1557 (19. February, 2003). Digital Globe 2016 and CNES/Astrium 2016 (11. January 2014). Othaya area, Kenya. 0° 31’ 30”S, 36° 58’ 01”E, elev 1885m Eye alt 3,35km. http://www.earth.google.com [Accessed on 7. April, 2016].

Haugerud, Angelique. 1989. “Land Tenure and Agrarian Change in Kenya.” *Africa* 59 (01): 61–90. doi:10.2307/1160764.

Kapkiyai, Jane J, Nancy K Karanja, Javaid N Qureshi, Paul C Smithson, and Paul L Woomer. 1999. “Soil Organic Matter and Nutrient Dynamics in a Kenyan Nitisol under Long-Term Fertilizer and Organic Input Management.” *Soil Biology and Biochemistry* 31 (13): 1773–82.

Kenya National Bureau of Statistics. 2009. “Population and Housing Census.”

Leakey, Louis. 2013. *Mau Mau and the Kikuyu*. Routledge.
Maxim Integrated, (2016): https://www.maximintegrated.com/en/app-notes/index.mvp/id/3808

Lott, J.E., C.K. Ong, and C.R. Black. 2009. “Understorey Microclimate and Crop Performance in a Grevillea Robusta-Based Agroforestry System in Semi-Arid Kenya.” *Agricultural and Forest Meteorology* 149 (6-7): 1140–51. doi:10.1016/j.agrformet.2009.02.002.

Lott, J. E., S. B. Howard, C. K. Ong, and C. R. Black. 2000. “Long-Term Productivity of a Grevillea Robusta-Based Overstorey Agroforestry System in Semi-Arid Kenya: II. Crop Growth and System Performance.” *Forest Ecology and Management* 139 (1): 187–201.

McNeely, Jeffrey A., and Götz Schroth. 2006. “Agroforestry and Biodiversity Conservation – Traditional Practices, Present Dynamics, and Lessons for the Future.” *Biodiversity and Conservation* 15 (2): 549–54. doi:10.1007/s10531-005-2087-3.

Meijer, Seline S., Delia Catacutan, Oluyede C. Ajayi, Gudeta W. Sileshi, and Maarten Nieuwenhuis. 2015. “The Role of Knowledge, Attitudes and Perceptions in the Uptake of Agricultural and Agroforestry Innovations among Smallholder Farmers in Sub-Saharan Africa.” *International Journal of Agricultural Sustainability* 13 (1): 40–54. doi:10.1080/14735903.2014.912493.

Muchiri, M. N., T. Pukkala, and J. Miina. 2002. “Modelling Trees’ Effect on Maize in the Grevillea Robusta+ Maize System in Central Kenya.” *Agroforestry Systems* 55 (2): 113–23.

Muturi, Phyllis M. 2017. “A REVIEW OF NYERI COUNTY-KENYA STRATEGIC PLAN

Omoro, L. M. A., and P. K. R. Nair. 1993. “Effects of Mulching with Multipurpose-Tree Prunings on Soil and Water Run-off under Semi-Arid Conditions in Kenya.” *Agroforestry Systems* 22 (3): 225–39.

Ong, C. K., C. R. Black, J. S. Wallace, A. A. H. Khan, J. E. Lott, N. A. Jackson, S. B. Howard, and D. M. Smith. 2000. “Productivity, Microclimate and Water Use in Grevillea Robusta-Based Agroforestry Systems on Hillslopes in Semi-Arid Kenya.” *Agriculture, Ecosystems & Environment* 80 (1): 121–41.

Othaya Climatic Data. 2016. Climate-Data.org. http://en.climate-data.org/.
Ovuka, Mira. 2000. “Land Use Changes in Central Kenya from the 1950s - A Possibility to Generalise?” *GeoJournal* 51 (3): 203–9

Pinard, F., E. Joetzjer, R. Kindt, and K. Kehlenbeck. 2014. “Are Coffee Agroforestry Systems Suitable for circa Situm Conservation of Indigenous Trees? A Case Study from Central Kenya.” *Biodiversity and Conservation* 23 (2): 467–95. doi:10.1007/s10531-013-0615-0.

Shannon, Claude E, and Warren Weaver. 1949. *The Mathematical Theory of Communication*. University of Illinois Press IL.

Shreffler, Karina M., and F. Nii-amoo Dodoo. 2009. “The Role of Intergenerational Transfers, Land, and Education in Fertility Transition in Rural Kenya: The Case of Nyeri District.” *Population and Environment* 30 (3): 75–92. doi:http://dx.doi.org.ep.fjernadgang.kb.dk/10.1007/s11111-009-0077-1.

Sørensen, Niels Kristian, and Anne Bülow-Olsen. 1994. “Plantedirektoratets F\a Elles Arbejdsmetoder for Jordbundsanalyser.”

Tengnäs, Bo. 1994. *Agroforestry Extension Manual for Kenya*. Nairobi, Kenya: International Centre for Research in Agroforestry.

Weil, et al. (2003). Estimating active carbon for soil quality assessment: a simplified method for laboratory and field use. *American Journal of Alternative Agriculture* 18(1): 3-17.

Yobterik, A. C., V. R. Timmer, and A. M. Gordon. 1994. “Screening Agroforestry Tree Mulches for Corn Growth: A Combined Soil Test, Pot Trial and Plant Analysis Approach.” *Agroforestry Systems* 25 (2): 153–66.

Appendices

Appendix I: Tabular overview of applied document

Table 4 Overview of applied methods

Applied method	Number	Details
Grand tour	3	Two with guides, one with elder
Field semistructured interview (SSI)	9	On-farm interviews
Key informant interview	2	Elder (Phillip Kibanga) and co-founder of Green Belt Movement (Lucy Waraguru Ndentu)
Questionnaire	30 farmers	
Focus Group Discussion	1	7 participants
Soil sampling	5 farms	3 sites at each farm, 3 replicates from each horizon, 3 full profiles at one farm
iButtons	1 farm	3 sites with 3 iButtons at each site
Species Richness Assessment	39 farms	Derived from trees reported in questionnaire, and observed in SSI
GPS	-	Wayfinding, plotting SSI, ground truthing of SSI farms
Remote sensing	-	For plotting GPS data, ground truthing and historical imagery

Appendix II: Main findings from Focus Group Discussion

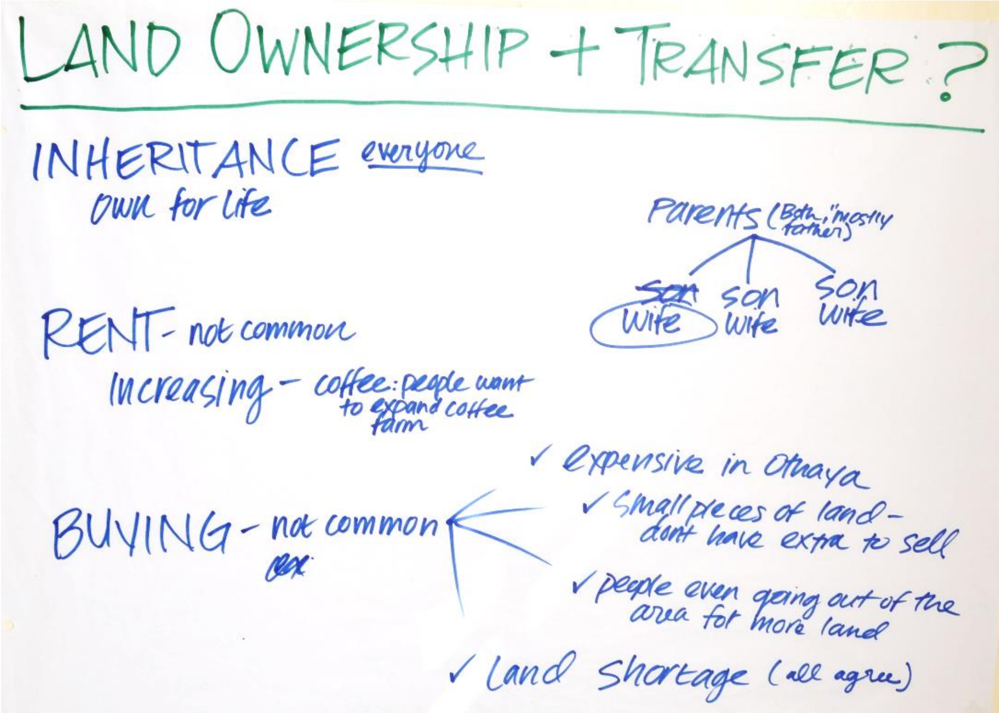

Figure 14 Key points about land ownership and land transfer recorded on posters during the FGD

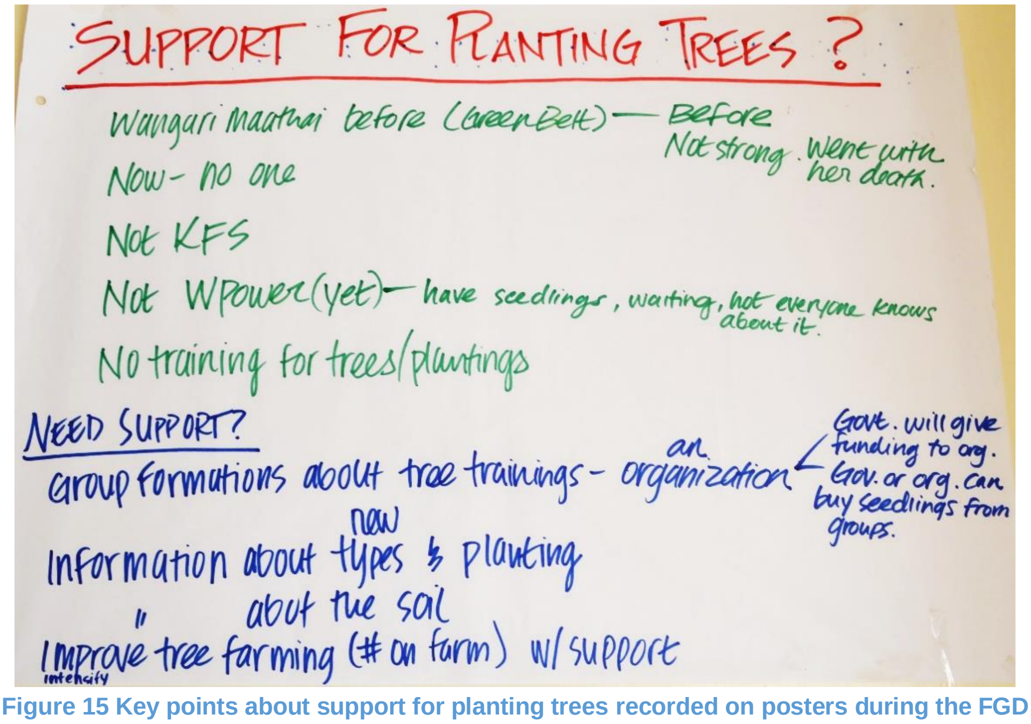

Figure 15 Key points about support for planting trees recorded on posters during the FGD

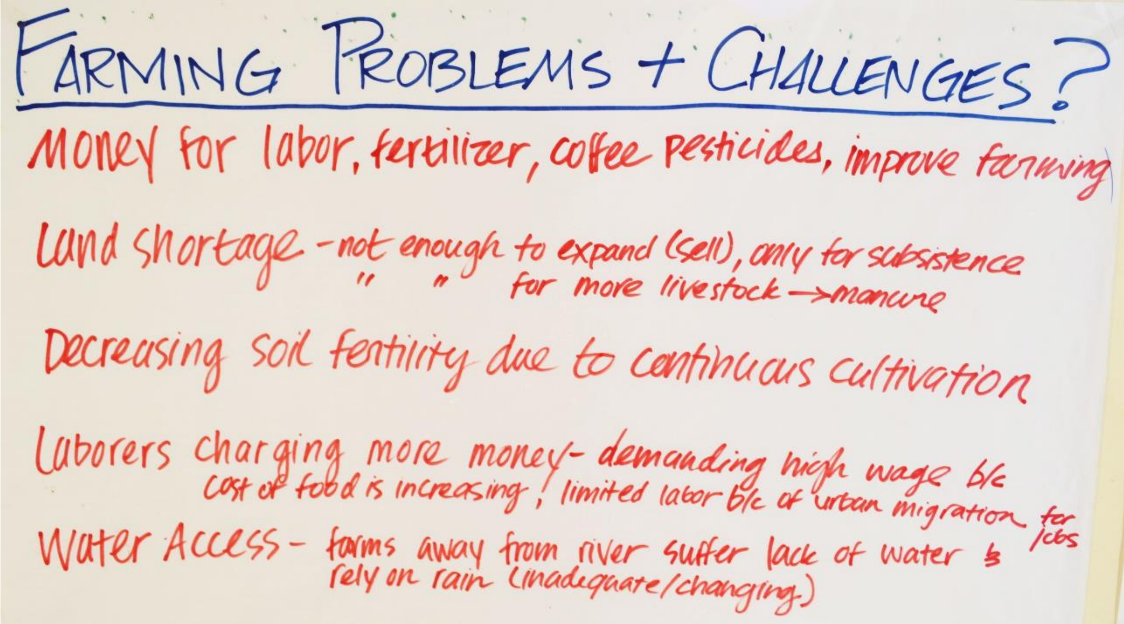

Figure 16 Key farming problems and challenges as recorded on posters during the FGD

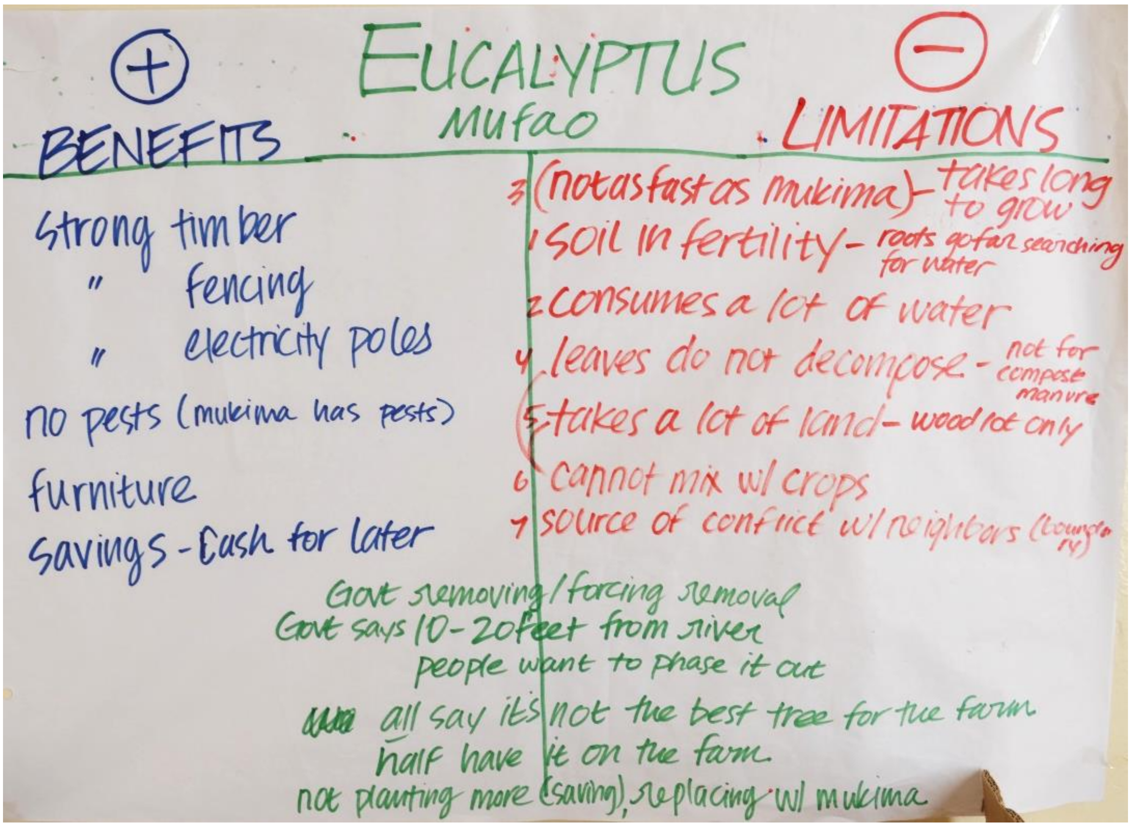

Figure 17 Mentioned benefits and liitations of eucalyptus as recorded on posters during the FGD

Appendix III: Farmer questionnaire

FARMER QUESTIONNAIRE

DATE AND TIME	
METHOD TYPE	
YOUR NAME	
PHOTO(S) #	
INFORMANT #	
INFORMANT NAME	
AGE	
GENDER	
MARITAL STATUS	
EDUCATION LEVEL	
OCCUPATION (continue if farmer)	
FARM SIZE	
AF/ FARM TYPE	
# PEOPLE IN THE HOUSEHOLD	
PHONE NUMBER	

1. **How large is your farm? (number of hectares or acres)**

   ____

2. **For how long has this land been farmed? (how many years)**

   ____

3. **What was here before it was a farm?**

   ____

4. **When did you acquire your farm? (year of acquisition)**

   ____

5. **From whom did acquire your farm? (rented __, inherited __, bought __)**

   ____

6. **How large was the farm of the previous owner? (number of acres or hectares)**

   ____

7. **How large was the farm of the owner before the previous owner (number of acres or hectares)**

   ____

8. **How steep is your farm compared to the rest of the village:**

   a) flat b) a little steep c) moderately steep d) very steep

9. **What crops do you grow on your farm throughout the year? (list)**

____
____
____
____
____

10. **Do you have trees on your farm?**

Yes No

9.1 If no, did you have trees before?

Yes No

Why?____________________________________
____
____
____

11. **What kind of trees do you have on your farm, what is each tree's purpose, and how are they arranged?**

Name of the tree	For which purpose(s)	Configuration	I / E
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

12. **What is the best tree on your farm and why?**
____
____

13. **Do you sell any of your crops? If yes, which ones? (list)**
____
____
____

14. **Does your household rely on income outside the farm?**

Yes No

14.1. If yes, what else do they do?

____

____

15. **Who is involved in the establishment of trees on your farm? (circle one)**

    Men Women Both

16. **Who owns the trees after establishment? (circle one)**

    Men Women Both

17. **Who manages trees on your farm? (circle one)**

    Men Women Both

18. **What are the main problems on your farm?**

    ____
    ____
    ____
    ____

Appendix IV: Demographic information of SSI and questionnaire respondents

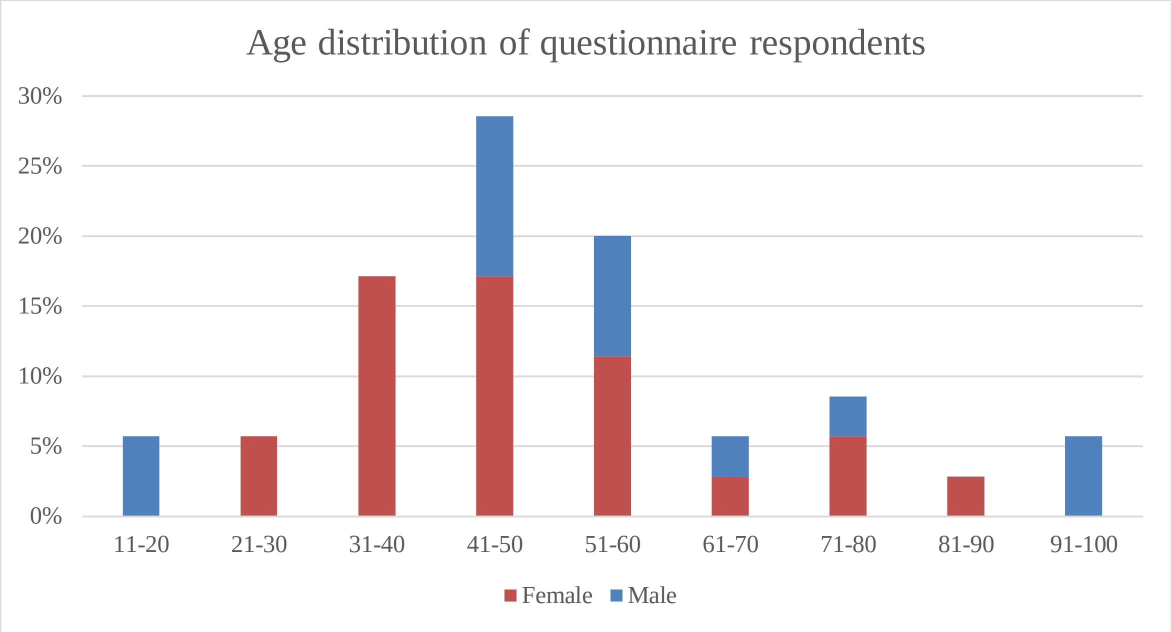

Figure 18 Distribution of questionnaire and SSI respondents by age and gender.

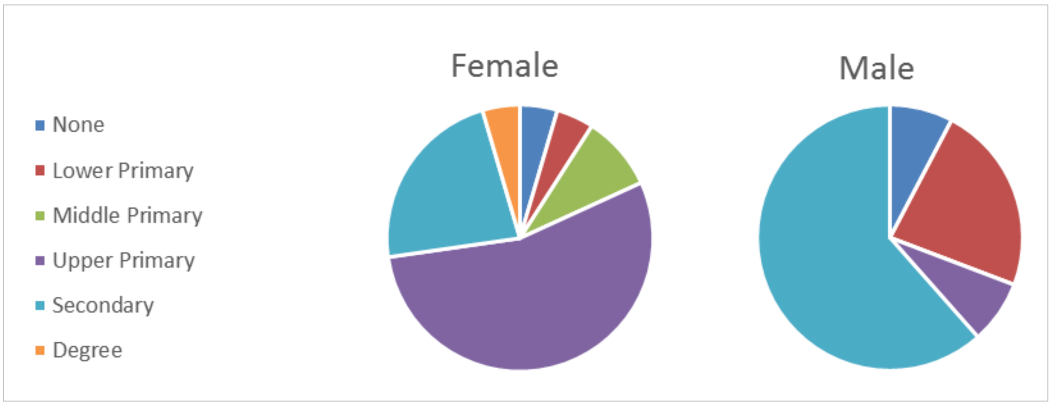

Figure 19 Education level of male and female questionnaire respondents and SSI participants.

Appendix V: SSI guide

Guide for semi-structured interview/walking interview

1. General information on household (to investigate the background/reasons behind practices)

1. How big is your household/how many people are there in your family (men, women, children)?
2. Who from the family work on the farm?
3. Do you hire labour for your farm?
    1. How many workers?
    2. When and for how long?
    3. For what purpose?
4. Do you or your family members work with off-farm activities?
    1. if yes: what do they do?

2. Farm information/ how the land size has changed

1. How big is your (this) farm?
2. How many farms do you have?
3. For how long have you had your farm?
4. Where/ from whom did you get your farm?
5. Has the farm size changed?
    1. Was the farm size different before you got it
        - How big was your father's or the previous owner's farm?
        - Your grandfather's or the previous owner's farm?
    2. Have you changed the farm size?
        - Have you divided the farm into smaller parts?
        - Have you lost/ gained/ sold some of the farm?
6. Do you get all the food and fuel you need from your own land?
    1. If no: how much land would you need to support you family? More trees? How many?
    2. Where do you get your fuelwood from? Can you get all of it on your own farm, are you self-sufficient? Income?

3. Overview of the agroforestry practices (what they do and why they do it)

Crops

1. What crops are you growing on this farm?
    1. What do you get from the crops? *(Products (subsistence/market), ecological, economic, sociocultural)*
2. Tell us about a typical cropping season/ year on this farm
    1. Rainy seasons
    2. Seasonal calendar (TEMPLATE)
3. How was the farm cultivated before you got it?
4. What products do you get from the farm, tree products, food products?
5. Do you use fallow periods?
    1. if yes: how often and how long are the fallow periods?

6. <u>Are you planning on continuing the same farming practices (system) or do you plan to change?</u>
7. <u>Why do you want to continue/Why do you want to change?</u>
    1. <u>If yes to change: what will you change? (size, crops, trees, use of it?)</u>

4. Trees

1. <u>Why do you have trees on your farm? Why not just crops?</u>
2. Have you always had trees on your farm?
    1. If yes, have you always had the same number and type of trees?
    2. If yes, how did you learn to farm with this system?
    3. If no, when and why did you start incorporating trees?
3. Who planted the trees on your farm?
4. What trees do you have on your farm?
5. What do you use **this** tree for?
6. How old is this tree/ When was this tree planted?
7. Why did you choose this tree and not others/ Why did you keep this tree?
8. How many trees (of each species) do you have?
9. <u>Is it possible to have more trees on this farm?</u>
    1. Do you plan to?
10. How do you propagate these trees?
11. Where do you get the seeds, seedlings, and cuttings from?
12. Are seeds, seedlings, and cuttings easy or difficult to access?
    1. Why?
13. Why do you plant your trees in this way (boundary, mixed or woodlot?) Why this amount and mixture?
    1. Why do you plant trees on the boundary?
    2. Why do you mix trees and crops?
    3. Why do you plant trees in a woodlot?
14. <u>What is the monetary value of the trees you have?</u>
15. <u>How do trees affect crops on your farm?</u>
16. <u>What are problematic trees?</u>
    1. What is the wrong with it?
    2. Do you have any on your farm?
    3. What do you do about it?
17. What are the benefits of having trees?
18. Do you sell timber? How much money do you get? How often?
19. Do you sell nuts/fruits? How much money do you get? How often?
20. Are there any trees you do not use for timber, fuel, charcoal, fodder, fruits/nuts (sale)? What is their use? Shy do you have them?

5. <u>Soil practice</u>

1. Please describe how do you manage your soil (use calendar?)
    1. Do you use fertilizer?
    2. Do you use manure?
    3. Do you use mulch/ green manure?
2. Do trees have an effect on the soil on this farm? What/ how?
3. Do you make compost manure with tree leaves?

6. Livestock

1. What animals do you have on your farm and how many?
2. What fodder do you use for the animals, do you get it from your own land?

3. Where do you keep your animals?
4. Do they graze? Where?
5. Do you use trees for fodder?

7. Problems and Challenges

1. <u>What are your main challenges/limitations?</u>
    1. What problems? (decreasing soil fertility, weeds, water?, coffee prices fluctuating)
    2. <u>What causes these problems?</u>
2. What are you doing to overcome the challenges?
3. What do you need to overcome the challenges?

8. Agroforestry Programs/Policies

1. <u>Are there any governmental or NGO programs about trees?</u>
2. Do you get any support to plant more trees?
    1. If yes, what kind and from whom?
3. What do you think about the Green Belt Movement?
    1. What is your perception of eucalyptus trees?

Appendix VI: List of all tree species found during the study

Table 5 List of all identified tree species during the course of the study with local, common, and scientific names. Tree origin is also illustrated. (Pinard 2014, Dharani 2002)

Local name	Common name	Scientific name	I/E
Apple	Apple	*Malus domestica*	Exotic
Avocado	Avocado	*Persea americana*	Exotic
Calliandra	Calliandra	*Calliandra calothyrsus*	Exotic
Muthithinda	Cypress	*Cupressus sp.*	Exotic
Eucalyptus	Blue gum	*Eucalyptus globulus*	Exotic
Fig	Fig	*Ficus sp.*	Indigenous
Guava	Guava	*Psidium guajava*	Exotic
Luguards	-	-	-
Macadamia	Macadamia	*Macadamia tetraphylla*	Exotic
Mango	Mango	*Mangifera indica*	Exotic
Mipuri	-	-	-
Miringamu	-	-	-
Muheheti	Knobwood	*Zanthoxylum usambarense*	Indigenous
Muhuti	Flame tree	*Erythrina abyssinica*	Indigenous
Muiri	Red stinkwood	*Prunus africana*	Indigenous
Mukima	Silky oak	*Grevillea robusta*	Exotic
Mukinduri	Croton	*Croton megalocarpus*	Indigenous
Mukungugu	NA	*Commiphora zimmermannii*	Indigenous
Mukurwe	Peacock flower	*Albizia gummifera*	Indigenous
Muringa	Large-leafed cordia	*Cordia africana*	Indigenous
Mutaru	Milk bush	*Euphorbia tirucalli*	Indigenous
Muthanduku	Black wattle	*Acacia mearnsii*	Exotic
Mutundu	Broad-leafed croton	*Croton macrostachyus*	Indigenous
Papaya	Papaya	*Carica papaya*	Exotic
Tree Tomato	Red pod terminalia	*Terminalia brownii*	Indigenous
Lemon	Lemon	*Citrus limon*	Exotic
Muderendu	Euclea	*Euclea divinorum*	Indigenous

Appendix VII: Humidity measurements

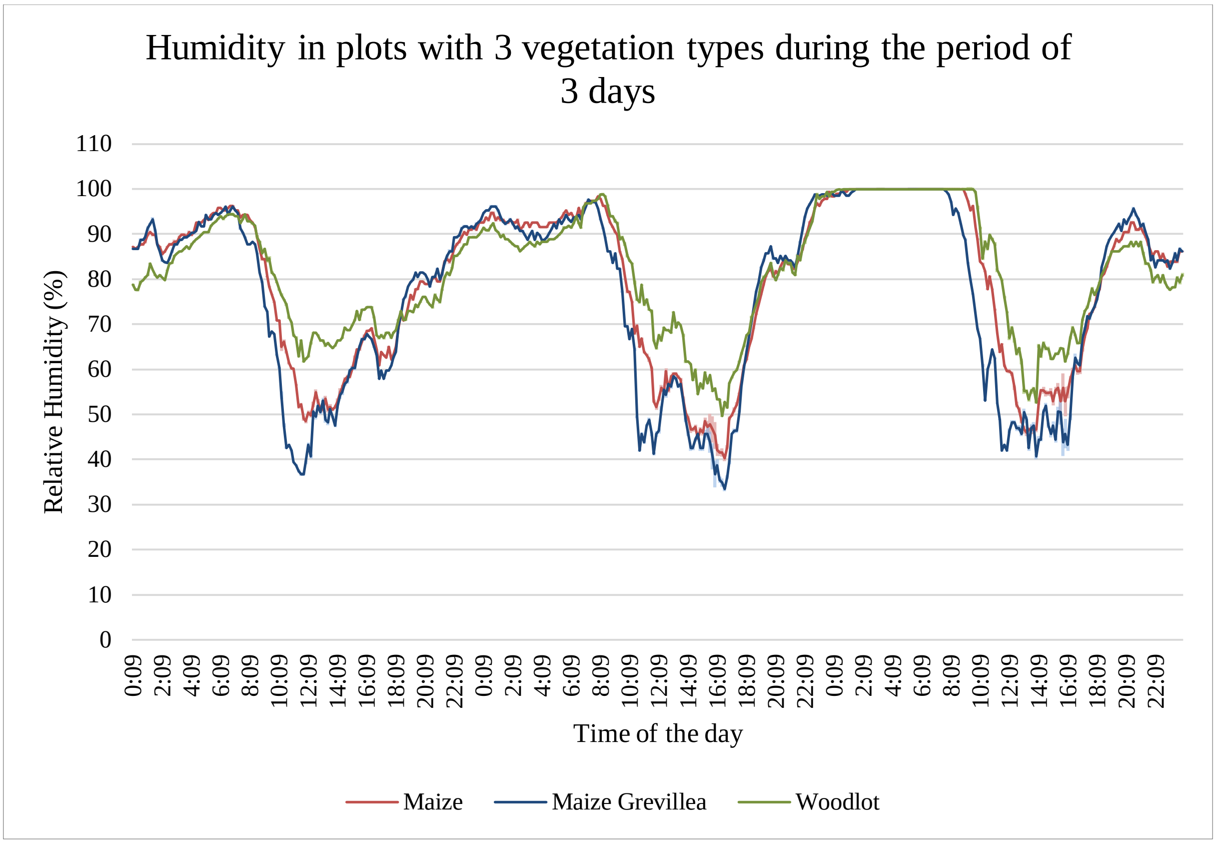

Figure 20 Humidity variations in 3 different vegetation types during the period of 72 hours. The light colored area around the lines represents standard error of the mean.

Appendix VIII: Soil analysis results

Bulk density

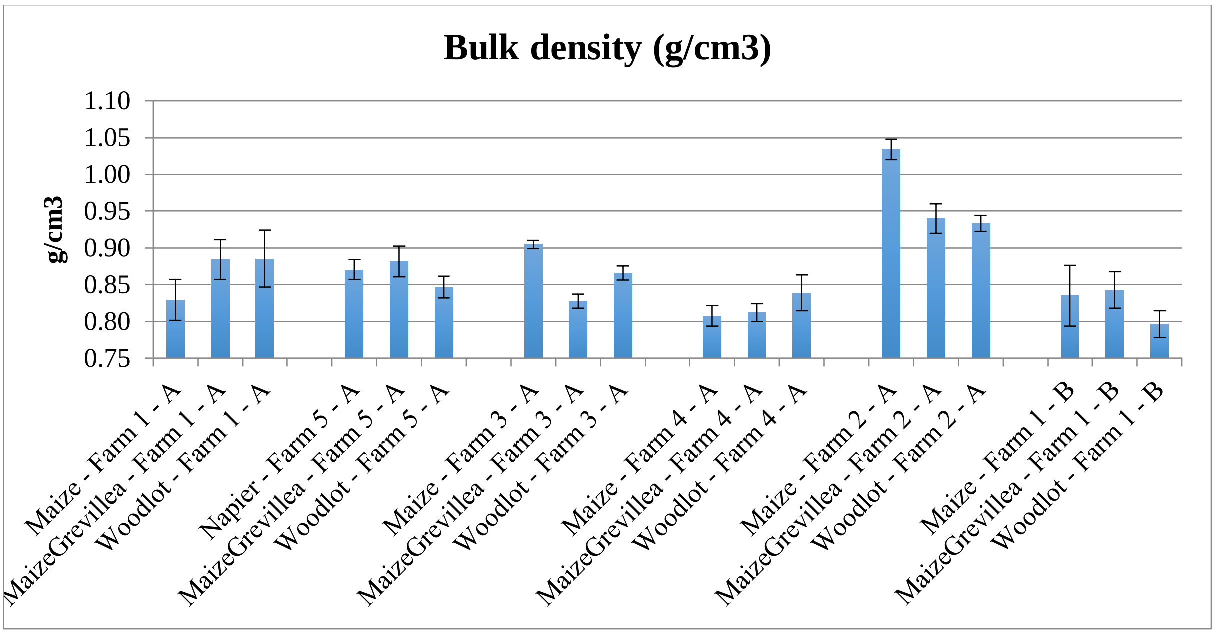

Figure 21 Bulk density of sampled soils calculated drom the oven dried soil from 100 cm^3 sampling rings. A represents A-horizon and B, B-horizon of the soil.

MnoxC

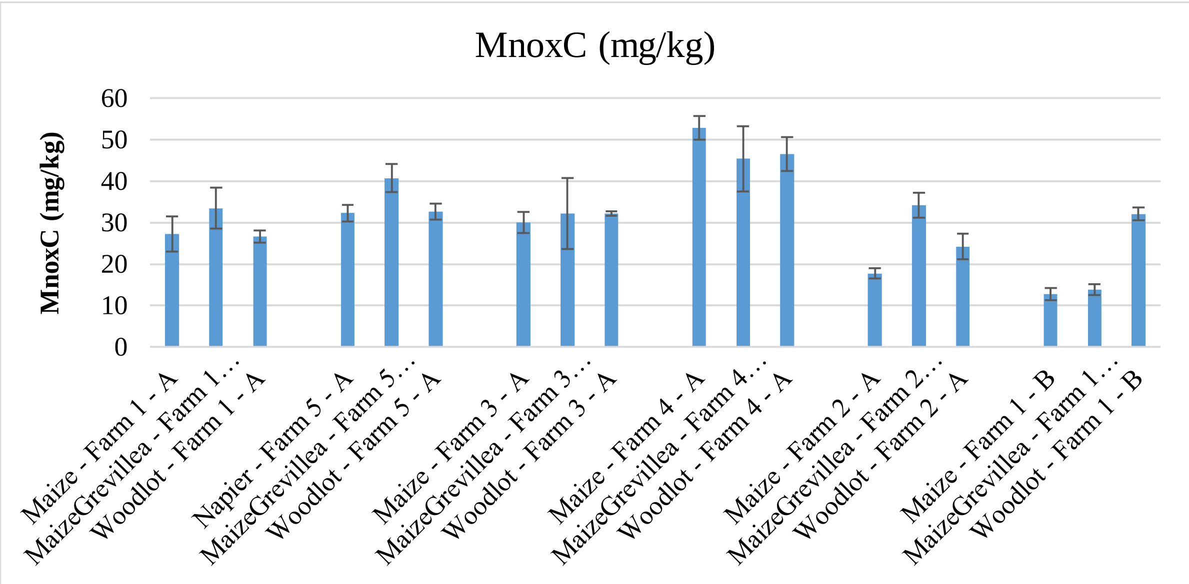

Figure 22 Content of permanganate oxidizable carbon in mg/kg. A represents A-horizon and B, B-horizon of the soil.

Carbon and nitrogen content

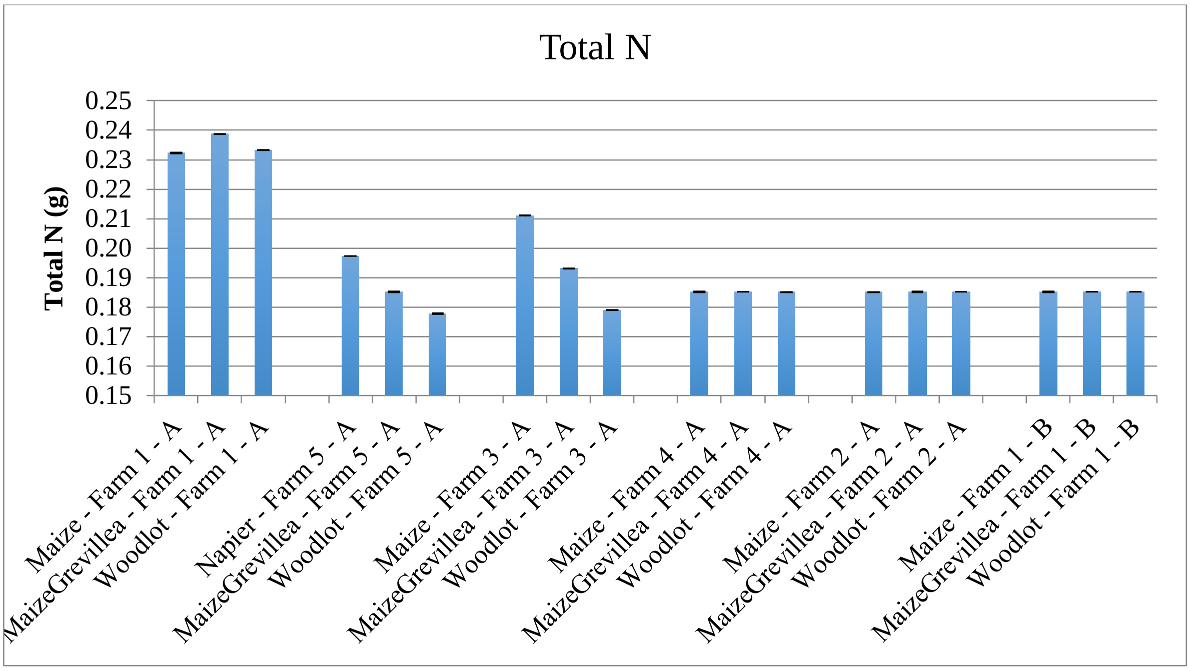

Figure 23 Total N calculated from N % and dry weight of the soil calculated as N(g) = dry weight (g)/100*Total N (%). A represents A-horizon and B, B-horizon of the soil.

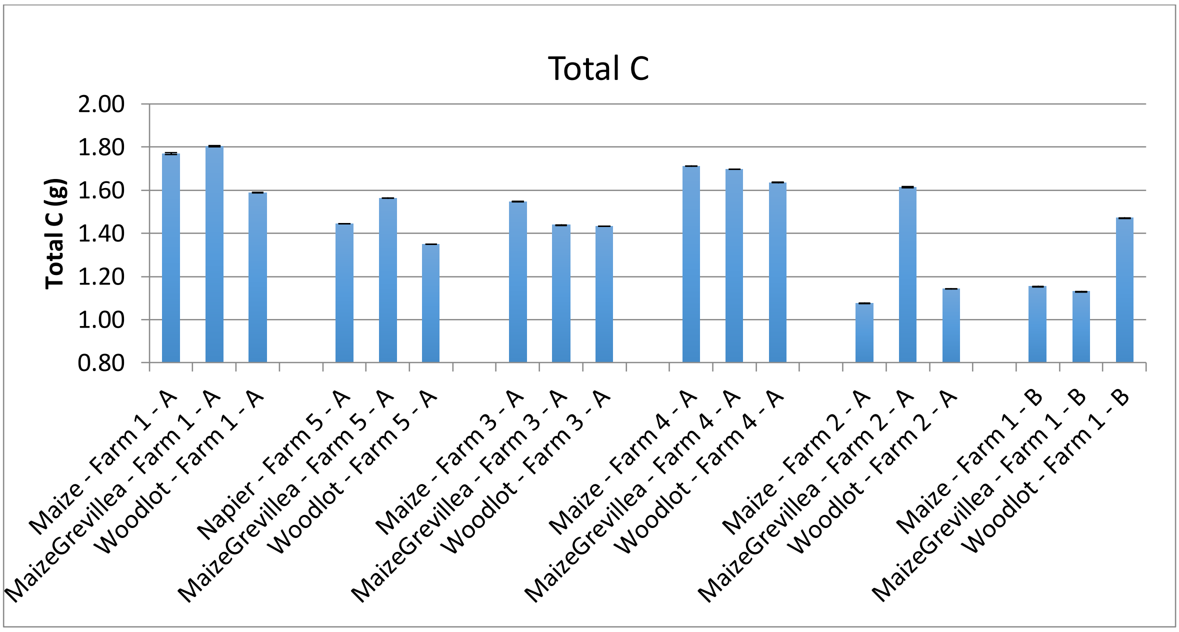

Figure 24 Total C calculated from C % and dry weight of the soil calculated as C(g) = dry weight (g)/100*Total C (%). A represents A-horizon and B, B-horizon of the soil.

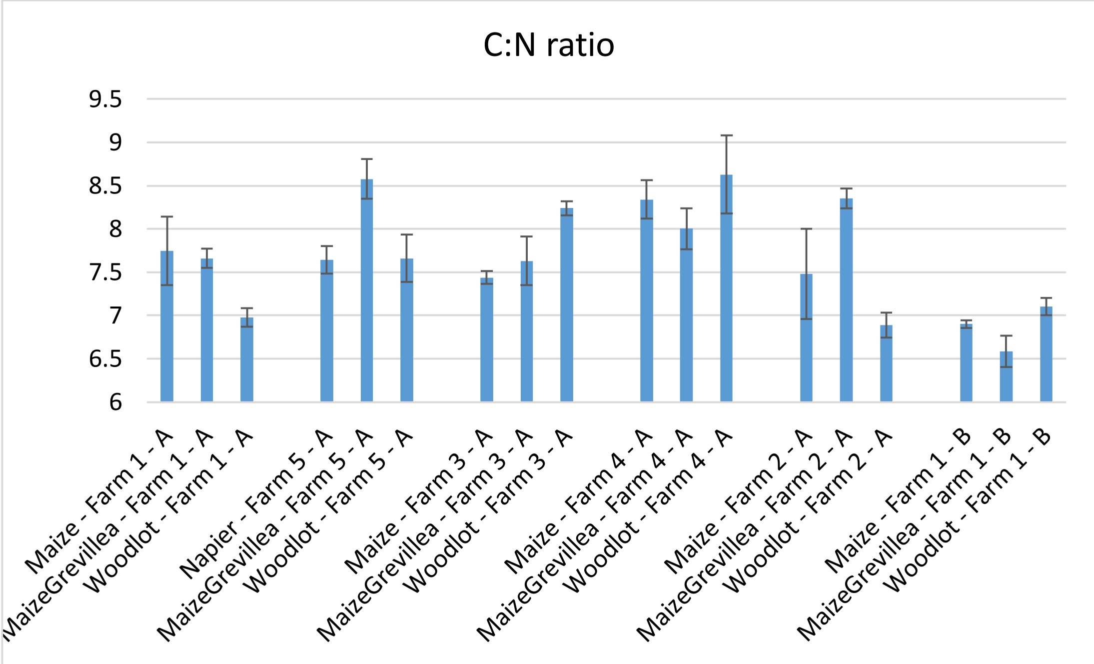

Figure 25 C:N ratio calculated from total N and total C content. A represents A-horizon and B, B-horizon of the soil

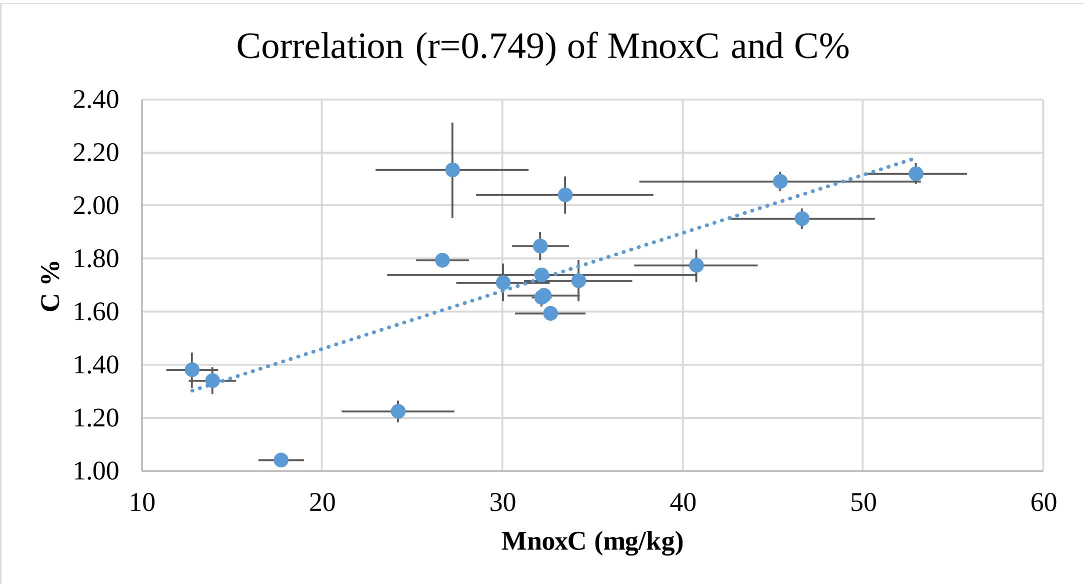

Figure 26 Graphical representation of positive correlation between MnoxC and total C in %, correlation is r=0,749.

Textural results

Table 6 Soil texture of sampled soils as determined by field method.

Plot	Texture
Farm 1	Silt loam (<10% clay)
Farm 1 (B-horizon)	Sandy loam (10-25% clay)
Farm 2	Silty clay (40-60% clay) in woodlot and heavy clay (>60%) in Maize and Maize Grevillea
Farm 3	Silt loam (<10% clay)
Farm 4	Silt loam (<10% clay)
Farm 5	Clay loam (25-40%)

Pictures from the field

Figure 27 Shiny surfaces as seen during the soil rofile study, characteristic for Nitisol soil type.