UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

# Agroforestry Practices in Gikirima, Embu County, Kenya

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# Abstract

Smallholder farmers relying on rain-fed agriculture are especially vulnerable to climate change, resulting in issues such as food insecurity. Agroforestry, an old farming practice which incorporates woody perennials, crops, and/or livestock, has shown to address these challenges. Trees on farms, provide multiple benefits such as carbon sequestration, erosion control, and diversified income. This study researches factors influencing smallholder farmers choice of agroforestry practices in Gikirima, Kenya, and their impacts on environmental and socioeconomic variables. Interdisciplinary field research involving data from 29 smallholder farmers about their farming practices, seven semi-structured interviews with agricultural officials and the elder of Gikirima, and soil pH and carbon content analysis on eight farms, revealed agroforestry as the main farming practice, along with acidic soils with high carbon content. Most farmers intercrop coffee with specifically macadamia and *Grevillea robusta*, as well as subsistence crops. Perspectives and recommendations of agroforestry practices varied among different agricultural institutions. We found that although the private institutions have a large power over the farming landscape and market, farmers still make their own decisions based off of their observations, experiences, and needs. However, it is necessary to conduct further research about agroforestry systems suitable for this area, the power the private institutions have over the farmers income, as well as, understanding which multipurpose indigenous tree species can be applied in order to move towards economic and environmental sustainability best suitable for smallholder farmers.

# Acknowledgements

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# Contents

# 1 Introduction

Climate change, food security, and sustainable livelihoods are found to be three main challenges sub-Saharan Africa (SSA) is currently facing and is expected to face in the future (Connolly-Boutin and Smit, 2016). These challenges are interconnected and therefore need to be understood as such (Ibid.). Unpredictable rainfall patterns and an increase in the severity and frequency of extreme weather events are, for example, to be expected as a result of climate change (IPCC, 2023). This affects food security through changes in yield and the amount and placement of arable land (Ringler et al., 2010). As an example, communities and farmers dependent on rain-fed agriculture are vulnerable to climatic shifts in the water cycle, which in turn poses considerable pressure on their livelihoods (Connolly-Boutin and Smit, 2016).

In SSA, farmers with holdings smaller than two hectares make up around 80% of agriculture and are known as smallholder farmers (Lowder et al., 2016). Smallholder farmers are directly dependent on natural resources (Lewis et al., 2018). Therefore, with the ongoing degradation of land and water resources, they are particularly vulnerable to the aforementioned challenges. This degradation, showing in e.g. soil erosion, deforestation, and siltation of waterways, is not new and farmers are continuously challenged to adapt to new climatic and socioeconomic circumstances (Shiferaw et al., 2009).

A practice known to be beneficial for smallholder farmers, because it addresses a range of environmental and socioeconomic challenges, is agroforestry (Bettles et al., 2021). Agroforestry systems vary widely in their execution, however, they all include the incorporation of woody perennials in crops and/or pastures for environmental, climatic, economic, and/or sociocultural benefits (Mbow et al., 2014). Studies have found that agroforestry practices can, among other things, combat deforestation, desertification, erosion, and decreasing soil fertility, while at the same time providing food, fuelwood, timber, and other ecosystem services (Shidiki et al., 2020). For these reasons, the adoption of agroforestry practices might make smallholder farmers better equipped to face the challenges of environmental and socioeconomic change.

Agroforestry practices already make up large parts of smallholder agricultural systems in SSA (Mbow et al., 2014), and around 29% of agricultural land in SSA is connected to agroforestry (Wanjira and Muriuki, 2020). This, however, is not new to the region. For several centuries some farmers have farmed within forests or trees, making use of tree products (Seddon, 1968). In the early 1900s, in Kenya specifically, the "shamba" system was introduced. This system is a form of Taungya, which combines the planting of forest trees with crops. The system, introduced during the colonial period, was mainly there to create exotic forest plantations. During the colonial period, the system worked by allocating forest plots to Kenyan farmers, who would clear the plot from indigenous plant coverage, so that the forest department could plant exotic trees there. In return, the farmers got to grow food crops on the plots for a defined period. This free, and thus cheap, labour for the exotic tree plantations was much needed as there was high demand for timber and fuelwood (Oduol, 1986).

During the early $20_{th}$ century, the exotic tree species grevillea and eucalyptus were introduced, with eucalyptus specifically introduced to supply fuelwood for the Kenya-Uganda railway (Muchiri, 2004; Oballa et al., 2010). Both trees were selected for their favorable characteristics for timber and fuelwood collection. In contrast to the perception of indigenous trees, they exhibit fast growth and offer good economic returns (Carsan et al., 2013;

Muchiri, 2004; Oballa et al., 2010). Presently, farmers continue to grow them for their quickly produced timber and fuelwood (Carsan et al., 2013). However, both of these exotic species have their drawbacks. Concerns have been raised regarding the adverse effects of growing eucalyptus near water sources due to its potential to dry streams, springs, and rivers, as well as its negative impact on biodiversity and soil fertility (Oballa et al., 2010). While grevillea has been found to, for example, reduce the aboveground biomass and yield of maize (Muchiri, 2004). Despite these drawbacks, both species are continuously grown in Kenya for their timber and fuelwood (Muchiri, 2004; Oballa et al., 2010). Other tree and plant species have been introduced to Kenya to become a part of a growing global market. Coffee was introduced to Kenya in the late $19_{th}$ century (Wanzala et al., 2022), and macadamia in the 1940s to diversify farmers' income (Maina et al., 2021). To this day the selling of coffee and macadamia nuts offers Kenyan smallholder farmers an important source of income (Quiroz et al., 2019; Wanzala et al., 2022), where Kenya, was the fifth largest producer of coffee in Africa in 2021 (Gichuru et al., 2021), and supplied 13% of the global macadamia market as of 2019 (Quiroz et al., 2019). Avocado has likewise experienced a boom in production for export from the 1970s and onwards (Griesbach, 2005).

Over time, different institutions have taken interest in promoting agroforestry on farms in Kenya for various reasons. The Ministry of Environment and Natural Resources, for example, wants to incorporate agroforestry systems to improve livelihoods and build environmental resilience. It states that different tree products can be used for subsistence and income, while also conserving soil and water resources (Ministry of Environment and Natural Resources, 2016). Further, the Kenyan Government is interested in the promotion because firstly, a regulation requires farms to have at least 10% of tree coverage (Ministry of Environment and Natural Resources, 2016) and secondly, the nation aims to plant 15 billion trees by 2032 (Koskei, 2023).

However, public/government agricultural extension services, which can enhance agricultural productivity (Kogo et al., 2021) and from which smallholder farmers have benefited (Kingiri A. N., 2021), are being privatized (Kyambo, 2022; Mumina and Bourne, 2020). Now the private sector, including private companies, non-governmental and farmers' organisations, participates in these extension services, which play a central part in the promotion of agroforestry on farms (Kyambo, 2022). This gives non-state actors more power, as institutions have an important influence on the adoption and execution of agroforestry through variables such as access to credit, inputs, and training (Kinyili et al., 2020; Musafiri et al., 2022). Growing market opportunities for commercial tree products with the support of private extension services could provide farmers with diversified income and the possibility of being contracted by private companies, which in turn would eliminate entry barriers to global markets (Amare et al., 2019). This integration of smallholders into the global market through partnership with companies is also known as a win-win scenario. However, such partnerships can entail certain risks as they are unequal in power, capital availability, and mobility. Oya (2009) finds that the win-win scenario often overlooks the local dynamics, the differences in interests, as well as the increased vulnerability of smallholders in such partnerships; as they often lead to an increase in resources for the more powerful actors, while smallholders end up with less decision-making power (Oya, 2009) .

In conclusion, smallholder farmers play a critical role when it comes to addressing key challenges, such as climate change, food security, and sustainable livelihoods in SSA. This is because they, firstly, are particularly vul-

nerable to environmental and socioeconomic shifts and secondly, make up large parts of the agricultural landscape in SSA. Through the integration of agroforestry practices on farms, smallholders may benefit by conserving natural resources and diversifying their income. However, there are complex dynamics in the adoption and promotion of such practices, as exotic cash crop trees have found their way into the global market. The privatization of agricultural extension services introduces new power dynamics, potentially amplifying inequalities as powerful actors benefit disproportionately. In light of this background, the purpose of this report is to gain a greater understanding of agroforestry in our case study area Gikirima, Embu County, Kenya. We want to explore agroforestry on farms, the influence of institutions on agroforestry, and the impact of it on environmental and socioeconomic variables. Particularly we want to answer the following research question(s):

*What factors influence smallholders' choice of agroforestry practices in Gikirima, Embu County, Kenya, and what impact do the selected agroforestry practices have on environmental and socioeconomic variables?*

1. *Which agroforestry practices are present?*
2. *How does the institutional context shape agroforestry?*
3. *How does agroforestry impact environmental and socioeconomic variables?*

# 2 Agroforestry Background

The environmental and socioeconomic benefits of incorporating trees on farms are widely acknowledged. Farmers can profit, e.g. through increased income and asset accumulation, availability of fuelwood on the farm, and greater milk yields through fodder shrubs (Hughes et al., 2020), while at the same time contributing to enhanced carbon sequestration, soil fertility, and biodiversity conservation (Sobola et al., 2015; Thorlakson and Neufeldt, 2012). As a result, agroforestry systems are seen as a crucial strategy to counter climate change and food security challenges in SSA (Mbow et al., 2014). However, it is important to differentiate between varying forms of agroforestry, which developed according to different ecological and socioeconomic conditions (Ibid.). In the following, based on Nair (2021) and Atangana (2014), a brief background of relevant aspects connected to our agroforestry research in Gikirima is provided (Atangana et al., 2014; Nair et al., 2021).

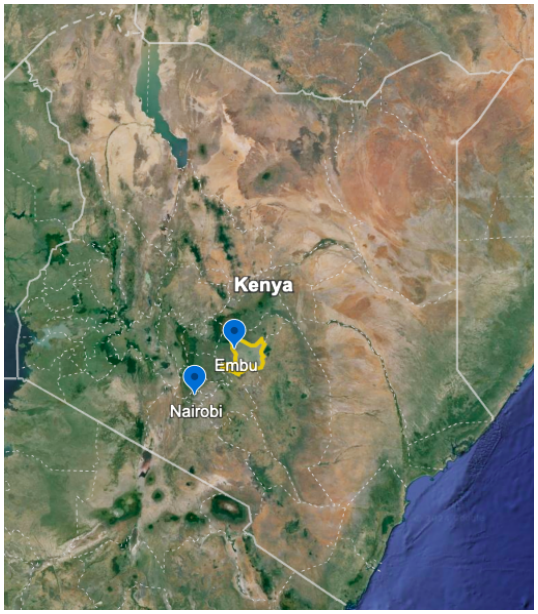
The term agroforestry encompasses a wide range of different tree/crop (and/or animal) combinations, from highly diverse-dense homegardens to simple, two-species plantation systems. This diversity of trees and crops, combined with the species selection, spatial and temporal arrangement pattern, and present management practices strongly impact the productive (e.g. food, fodder, and wood) and protective (e.g. soil and biodiversity conservation) functions of the system. Different tree species, for example, are found to differently impact soil and microclimate factors due to their varying height, crown shape and density, root systems, and litterfall. Therefore, trees can have diverse positive and negative effects on crops, depending on tree age and species, environmental conditions, crops' physiology, and spacing. Spatial arrangement patterns include alley-cropping, where trees are planted in rows alongside crops, structured or unstructured intercropping, where trees are integrated into fields of crops with consistent or varying spacing, and placement along boundaries as windbreak or border markers. Concerning the environmental effect of trees, their value for enhancing soil fertility through nutrient cycling, erosion control, phosphorus availability (through mycorrhiza), and nitrogen fixation (legume trees) is acknowledged; while indigenous trees can also be crucial for biodiversity conservation. Furthermore, studies confirm the increased carbon storage capacity by incorporating trees on farms (Lugo-Pérez et al., 2023) and the potential of trees to elevate pH values in Embu, Kenya (Ndlovu, 2013).

# 3 Study Site

This research was conducted in Gikirima village, located in Kibugu in Embu county, central Kenya, from 1st March to 12th March 2024 (Fig.1a). Kibugu town is close to the Mount Kenya area, around 150km north-east of Nairobi. In Embu county 70% of the population is employed in the agricultural sector, with Kibugu being an agriculturally productive sub-county. The main cash crops in this county are coffee, tea, macadamia, and miraa (County Government of Embu, 2023).

Gikirima village is around 2.6 km away from Kibugu and is located around 1800m above sea level (Fig. 1b). It has quite a consistent daily mean temperature throughout the year between circa 21°C and 25°C. However, the average low temperature can reach around 14°C in December and the average high temperature nearly 30°C in February (Weather and Climate, 2024). There is an annual rainfall of around 1900mm (SUCAFINA, 2020). The area experiences bimodal rainfall with rains from March to May, and again in October to December. Gikirima is 1.35km$^2$ and consists mainly of one 1.3km long road, which connects around 76 households. The population is around 250-300 (considering that the average household size in Embu is 3.3 (HURUmap, 2019). The soil is clayey and the dominating soil type is nitisols, which are described as well-drained, red tropical soils (Piikki et al., 2016).

The moderate temperature, large amount of rainfall, and well-draining soil provide a good environment for agriculture. The main cash crops in Gikirima are coffee, tea, and macadamia (survey, elder).




**(a)** Showing Kenya with Embu county highlighted in yellow. The capital Nairobi and the county capital, Embu, are shown with blue points. *Google Earth (Authors' work).*


**(b)** Gikirima Village marked with a red outline, the study site in Kenya. *Google Earth (Authors' work).*

**Figure 1:** Study site.

# 4 Methods

In the following section, we outline the research methods we utilized. For both interview and survey methods, we obtained informed consent from all participants prior to their involvement. Participants were provided with information regarding the purpose, procedures, and confidentiality measures of the study. We also informed them of their right to decline to answer questions or to terminate the interview/survey early, if they wished.

## 4.1 Interviews

An overview over the methods used as well as the amount of participants can be found in Appendix I. Furthermore, the interview guides for the semi-structured interviews can be found in Appendix II.

### 4.1.1 Open-ended Interview with an Elder

For an overview of the study area and to gain insights into local perspectives, we conducted an unstructured interview with the village elder of Gikirima. The interview was held in person and lasted approximately one hour. Open-ended questions were used to facilitate a free-flowing conversation. Answers were noted manually during the interview. We employed narrative analysis to analyze the interview, focusing on identifying themes and patterns within the elder's narratives.

### 4.1.2 Semi-structured Interview with Government and Company Officials

In order to gain a better understanding of influential institutions present in our research area and their possible impact on farmers' decision-making concerning agroforestry practices in Gikirima, we conducted semi-structured interviews (SSIs) with governmental and private sector officials. This included an agricultural extension officer of Embu County, an environmental and climate change officer of Manyatta Sub-county, the manager of Kibugu Farmers Co-operative Society, an official of LIMBUA Company, the manager and manager assistant of Gikirima Coffee Factory, and an official of Kathangariri Tea Factory. The private institutions are shortly outlined in Table 2 2. The relevance of these institutions was determined at the beginning of our study, in the open-ended interview with a Gikirima elder, in informal chats with other farmers in Gikirima, as well as through our household surveys. Institutions influencing agroforestry in Gikirima, however, are not limited to the ones we managed to interview but include, among others, the Community Forest Association and the Rainforest Alliance. We conducted all interviews in person. The one to two-hour-long interviews consisted of predetermined questions, developed by us based on prior research and consultation with experts in the field. Follow-up questions were asked to clarify responses or explore relevant topics further. We either recorded interviews or took notes, transcribing them later for analysis. The analysis consisted of a thematical analysis in NVivo with the following codes, which were identified inductively: "Eucalyptus", "Fertilizers", "Grevillea", "Intercropping and Agroforestry", "LIMBUA", "Memberships and Governmental Institutions", "Mulching", "Seedlings", "Soil", "Training", "Tree choice" and "Trees for non-economic reasons".

## 4.2 Surveys

We conducted a general survey with Gikirima farmers to gather insights into various agroforestry systems and practices, including their motivations for incorporating trees and specific tree species, as well as their perceived impacts on environmental and socio-economic factors. To get an overview of agroforestry in this area, we examined the presence of crops, trees, and livestock on the farms, as well as the spatial arrangement of trees, intercropping strategies, and management practices. When relevant, follow-up questions were posed, and responses were recorded separately. Survey questions were developed based on information acquired from a range of sources, including academic literature, reports, the interview with the elder, and six preliminary test trials aimed at refining question clarity and relevance.

To select participants, we adopted a two-stage sampling approach. Initially, we identified the first 20 farms through systematic sampling, selecting every third household based on location. Subsequently, an additional 10 farms were chosen through convenience sampling with the assistance of local guides. Farms that hosted us or were part of the preliminary test trials were excluded from the sampling to avoid bias. A total of 29 farms were surveyed. Each survey, which included e.g. questions about the farmer and farm demographics, agroforestry systems, and management practices, took approximately 30 minutes to complete.

Analysis of the surveys consisted of descriptive statistics, which were summarized in graphs using the program Excel. We analyzed the qualitative answers from follow-up questions thematically with the same codes that were used for the semi-structured interviews with government and company officials.

## 4.3 Soil Analysis

We collected soil samples to investigate potential differences in carbon content and pH values between coffee with and without trees. A total of eight farms were selected for sampling based on convenience. On each farm we collected two homogeneous soil mixture samples. These samples were taken from five different spots within a 3m x 3m plot, including the four corners and the middle, using a soil sampler probe. The first sample plot always included a higher density of trees within and around it, while the second sample plot allowed for low to zero tree densities. Tree numbers and species within and around the plots were noted. Whenever possible we collected soil samples at the same height on the slope. Afterwards, we dried the soil samples outside in the sun and again upon arrival in the laboratory. In the laboratory pH and carbon values were measured following standard procedures.

# 5 Results

## 5.1 Agroforestry Practices in Gikirima

In order to understand the farmers' incentives of their agroforestry practices, it is necessary to firstly understand how the farms are arranged. Therefore, this section will provide an overview of the farms, and intercropping and management practices, as well as the soil properties.

Based on our preliminary survey test trial, we decided to focus our general survey on the main crops, trees, fodder crops, and livestock identified. These were: maize (*Zea mays ssp.*), banana (*Musa ssp.*), taro (*Colocasia esculenta ssp.*), passion fruit (*Passiflora edulis ssp.*), macadamia (*Macadamia integrifolia ssp.*), avocado (*Persea americana ssp.*), mango (*Mangifera indica ssp.*), tree tomato (*Solanum betaceum ssp.*), grevillea (*Grevillea robusta*), eucalyptus (*Eucalyptus ssp.*), napier grass (*Pennisetum purpureum ssp.*), calliandra (*Calliandra calothyrsus*), tithonia (*Tithonia diversifolia ssp.*), cows, goats, chickens, geese, rabbits, and pigs.

### 5.1.1 Overview of Farms

We found the average farm size in Gikirima to be 1.12 acres with an average tree density of 55 trees per acre (n=26). Smaller farms tended to have a higher tree density compared to larger farms (Fig. 2). Coffee cultivation was present on all farms, and tea was cultivated on 69% (n=29). Coffee and tea were exclusively used for selling purposes. Additionally, all farmers grew banana, most planted maize and taro, and nearly half grew passion fruit vines (Fig. 3).

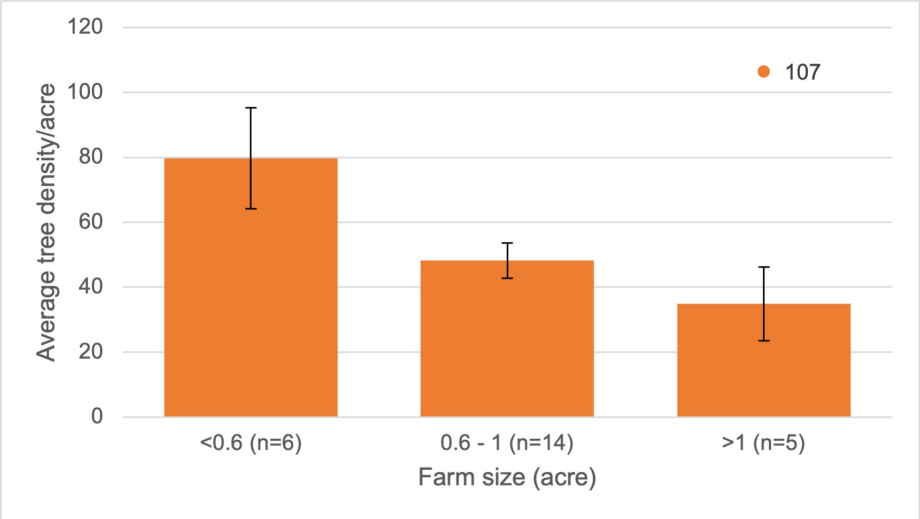



**Figure 2:** The average tree density per acre for three different farm size ranges in Gikirima, Kenya. Standard error bars are shown in black. One farm was plotted as an outlier, as it disproportionately skewed the graph.

Maize and taro, two common food crops, were used mainly for subsistence. The most common food crop, banana, was planted for subsistence and selling. Some farmers mentioned that if they had too much of the crop to eat themselves, they would sell it. Passion fruit on the other hand, was mainly planted for subsistence (Fig. 4).

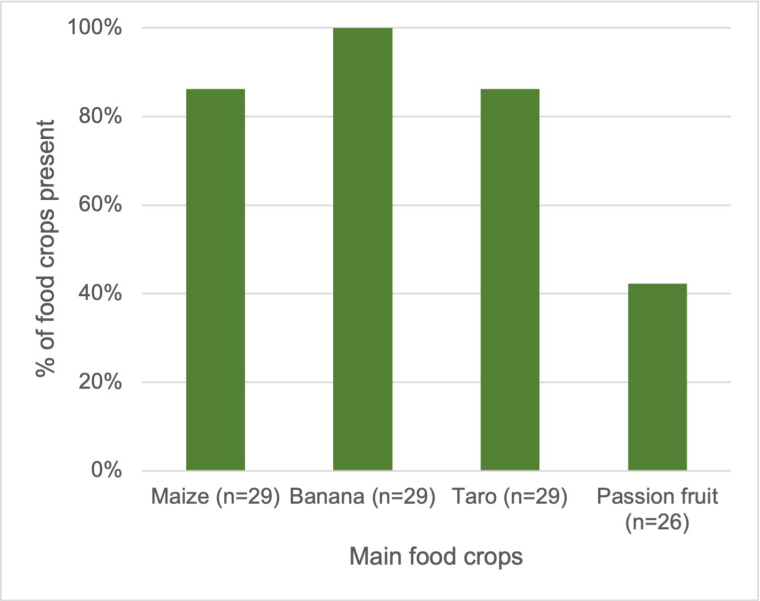



**Figure 3:** Presence of main food crops on farms in Gikirima, Kenya.

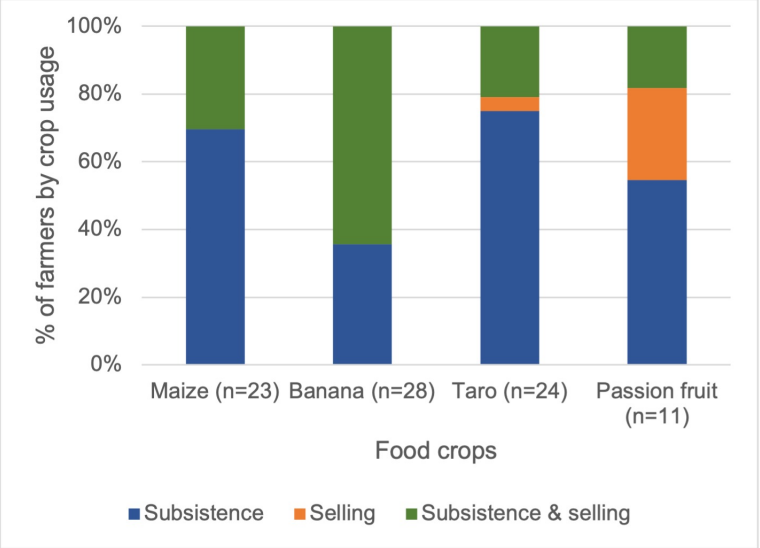



**Figure 4:** Farmers in Gikirima using main crops for either subsistence, selling or both.

Other food crops mentioned by farmers were beans, potato, sweet potato, sugarcane, and cabbage (survey). Concerning tree cultivation, nearly all farmers had macadamia, avocado, and grevillea trees, whereas around half of the farmers had mango and/or eucalyptus (Fig. 5). Some farmers mentioned planting both native and exotic varieties of avocado and mango on their farm. Only one farmer mentioned having a different indigenous tree, moringa (*Moringa oleifera*), however, we observed this tree on several farms.

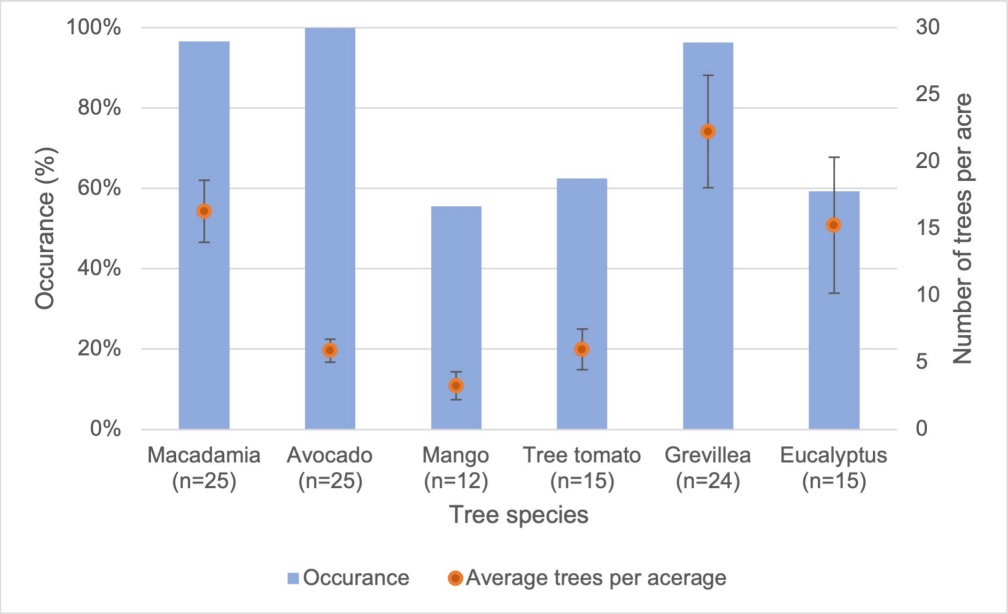



**Figure 5:** The occurrence and frequency of different tree species on farms in Gikirima. Standard error bars are shown in black.

Mango and tree tomato trees were used by most farmers for subsistence only, while most farmers solely sold their macadamia nuts. Avocado fruits, as well as the timber and firewood from grevillea and eucalyptus, were used by approximately half the farmers for both selling and subsistence, while the remaining farmers used it either for selling or subsistence alone (Fig. 6). On the other hand, the most common food crops on the farms were mainly used for the farmers' own subsistence and sold when abundance allowed.

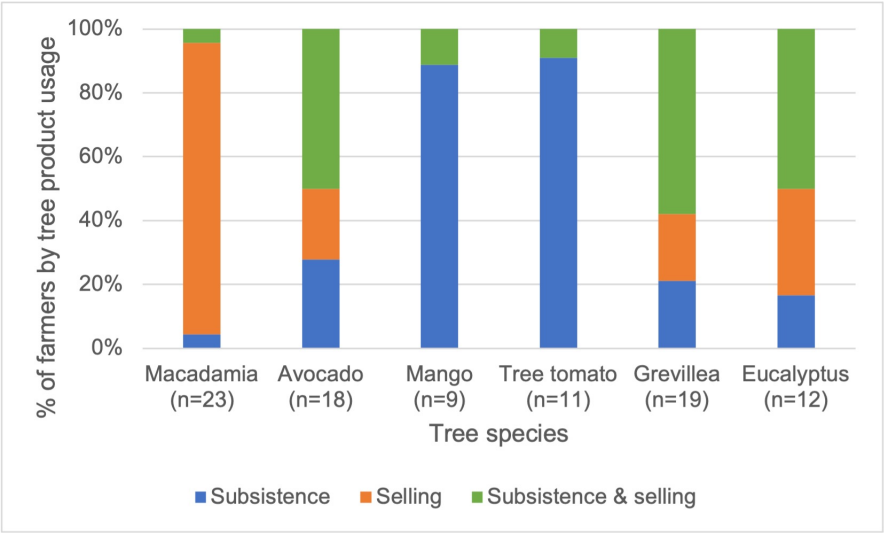



**Figure 6:** Farmers in Gikirima using tree products for either subsistence, selling or both.

The main livestock we observed on the farms were chickens, cows, and goats. Less than 20% of farms had geese, rabbits, and pigs (see Appendix IV). All farms grew napier grass, while around half also had calliandra and tithonia. Additionally, 59% of farmers used crop leftovers, such as maize stalks, banana leaves and stems, and sweet potato stalks, as fodder for their livestock (see Appendix IV).

### 5.1.2 Intercropping and Spatial Arrangement

In Gikirima, we found that the main tree species used by farmers for intercropping were macadamia, avocado, and grevillea trees (Table 1). Nearly all farmers intercropped coffee with grevillea. These were either scattered on the farms, alley-cropped, planted as boundary trees, or separately (Fig. 8). Two farmers (19 and 27) explained to us that coffee grew well together with grevillea trees and that they did not affect the coffee stems. One farmer (5) reported the soil being more black, which is an indicator of fertility, around her grevillea trees. Another farmer (21), on the other hand, stated that grevillea trees affected the soil negatively. Hence, he only uses them as boundary trees or for windbreaks. Two farmers (4 and 26) told us that grevillea trees provide too much shade on the coffee, but reduce this effect by cutting them down when they get too big. Several farmers also grew subsistence crops, such as kale and pumpkin, together with coffee, grevillea, and macadamia (farm 7).


**Figure 7:** Grevillea as a boundary tree inbetween farms. (Photo: Emily Faye) *Modified*.

**Table 1:** Different intercropping practices found in Gikirima, Kenya. The second row (practice intercropping) shows how many farmers practice intercropping with a specific tree species. After that the table shows how many farmers practice intercropping between specific food crops and tree species.

| **Crops** | **Macadamia** | **Avocado** | **Grevillea** | **Eucalyptus** | **Mango** |
|---|---|---|---|---|---|
| *Practice intercropping* | *79% (n=28)* | *50% (n=20)* | *69% (n=26)* | *6.5% (n=16)* | *43% (n=7)* |
| Coffee | 95% (n=22) | 40% (n=10) | 75% (n=16) | 0% | NA |
| Banana | 9% (n=22) | 10% (n=10) | 0 (n=16) | 0% | NA |
| Napier grass | 9% (n=22) | 10% (n=10) | 6.3% (n=16) | 1 farmers | NA |
| Other trees | 4.5% (n=22) (avocado) | 10% (n=10) (tree tomato) | 6.3% (n=16) (avocado) | 0% | NA |
| Other crops (maize, beans, pumpkin, passionfruit, yam, cassava, tea | 18% (n=22) | 50% (n=10) | 12.5% (n=16) | 0% | NA |

Eucalyptus was mostly placed in woodlots or serving as a boundary (Fig. 8). Farmers had different reasons for not intercropping eucalyptus. Some farmers explained that eucalyptus had a high water usage and drained the soils of water (farm 8 and 21). Other farmers, on the other hand, told us that they did not experience issues with the water usage of eucalyptus (farm 7 and 10). For them it was rather an issue of eucalyptus' roots spreading and competing with crops for nutrients (farm 5, 7, 10, 26 and 29). One farmer also chose not to intercrop eucalyptus because of the risk of branches falling down from a distance when harvesting crops underneath (farm 19). Although most farmers did not intercrop eucalyptus, we spoke to one farmer who intercropped eucalyptus and napier grass (farm 28). On another farm, four eucalyptus trees were scattered around the farm "in a way which does not affect the crops". The presence of eucalyptus at this farm was due to natural seed dispersal (farm 12).

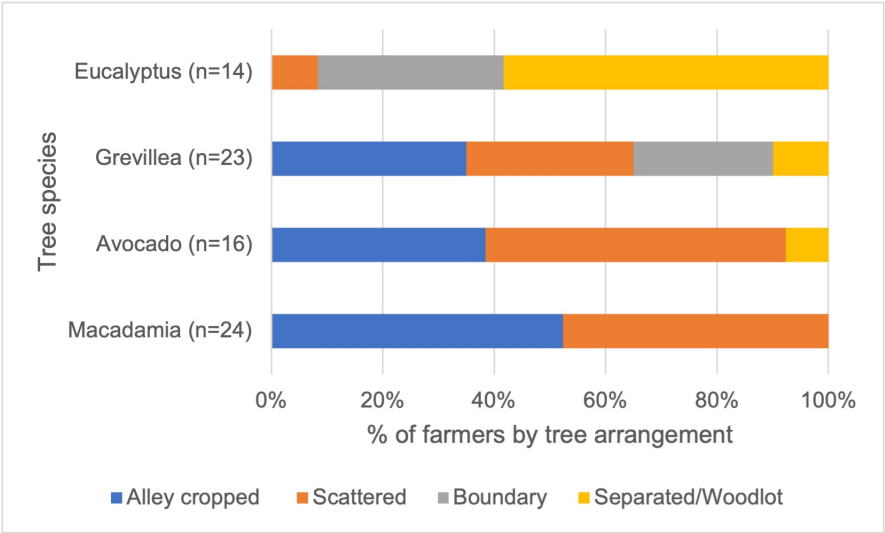



**Figure 8:** The arrangement of different tree species on the farms in Gikirima, either being: alley cropped, scattered, boundary or separated/woodlot.

We found that coffee, napier grass, maize, and other subsistence crops were often intercropped with macadamia and avocado trees. Examples of this intercropping can be seen on Fig. 9. All but one farmer (farm 3) intercropped

macadamia with coffee. One half of the farmers practiced alley cropping, while the other half placed them scattered around the farm. Avocado was mainly scattered and alley cropped (Fig. 8). Several farmers mentioned that macadamia, and particularly avocado trees with their large canopy, provided a lot of shade hindering productive coffee cultivation (farm 8, 13, 17 & 27). Farmers 13 and 5 stated that coffee was affected by being intercropped with macadamia trees but was fine when manure was applied.


**(a)** Macadamia and coffee intercropped.

**(b)** Coffee, macadamia, avocado, and other subsistence crops intercropped.

**Figure 9:** Examples of intercropping on farms in Gikirima. (photo: Yasmin B. Versi). *Modified*

### 5.1.3 Management Practices

In Girkirima, macadamia, avocado, grevillea, and eucalyptus trees were all pruned. For macadamia, grevillea, and eucalyptus trees, all but one farmer used the prunings from the trees (n=16, n=17, and n=7 respectively). For avocado all but two farmers used the prunings (n=17). Prunings from all the trees were largely used for firewood and mulching purposes. In the survey, 15 farmers mentioned mulching with at least one species of tree leaves. Several farmers told us that avocado leaves decompose easily and provide fertile soil (farm 19 and 5). Macadamia leaves were also used by farmers for mulching (farm 1, 4, 9, 25, 26 and 28), but several farmers chose to compost macadamia leaves, e.g. by mixing them into manure (farm 19, 3 and 27). We found that also grevillea leaves were used by farmers for mulching, whereas eucalyptus leaves were less frequently used for that purpose (farm 11 and 5). Two farmers said that eucalyptus leaves destroy the soil, one of them attributing this to them being acidic (farm 23 and 28). Others told us that eucalyptus leaves take a long time to decompose and prevent water from penetrating the soil (farm 3 and 19). Lastly, two farmers told us that they burn eucalyptus leaves, one because they destroy the

soil and the other to improve the water infiltration of their soil (farm 28 and 3, respectively).

Further management practices, we researched, were the soil fertilization practices. In Gikirima, all but farm 20 fertilized their soil with either manure, compost, and/or inorganic fertilizer. All farmers (except farmer 20) used manure from their own cows/farm. 50% of farmers also applied compost, which they gathered from their own farms in the form of leaves from prunings or droppings. Farmer 19 mixed ash from firewood into composted manure. Inorganic fertilizer was also widely applied (86%).

### 5.1.4 Soil Carbon Content and pH

We found that overall, the pH in Gikirima was acidic, with the lowest value being 4.4 (farm 7) and the highest 5.7 (farm 19) (n=8) (Fig. 10). This aligns with the remark, made by farmer 4, that soils in the area are very acidic. It also fits with the account of the agricultural extension officer mentioning that soils are becoming more acidic. He mentioned that when using inorganic fertilizer, the supplementary lime should be applied. But mainly he blamed the acidic soils on the lack of organic fertilizer or manure application.

We found that the pH in all soil samples did not greatly differ between samples taken on the same farm in low-tree-density plots (LTD) and samples in high-tree-density plots (HTD). In five of the eight farms the pH was slightly higher in the HTD compared to its counter LTD part. The biggest difference was found on farm 7, with the pH of the HTD being 0.8 higher than in the LTD. This difference might result from the HTD sample being taken further up the slope than the LTD. It also had a very high tree density (2 grevillea, 2 macadamia and several trees close to the plot) compared to the LTD with no trees in nor close to it. On farm 3, the difference between HTD and LTD was 0.7 and on farm 27, it was -0.4. We were unable to connect these differences to any of the additional notes we took. On all other farms the pH between the HTD and LTD did not differ more than an absolute value of 0.2 (Fig. 10).

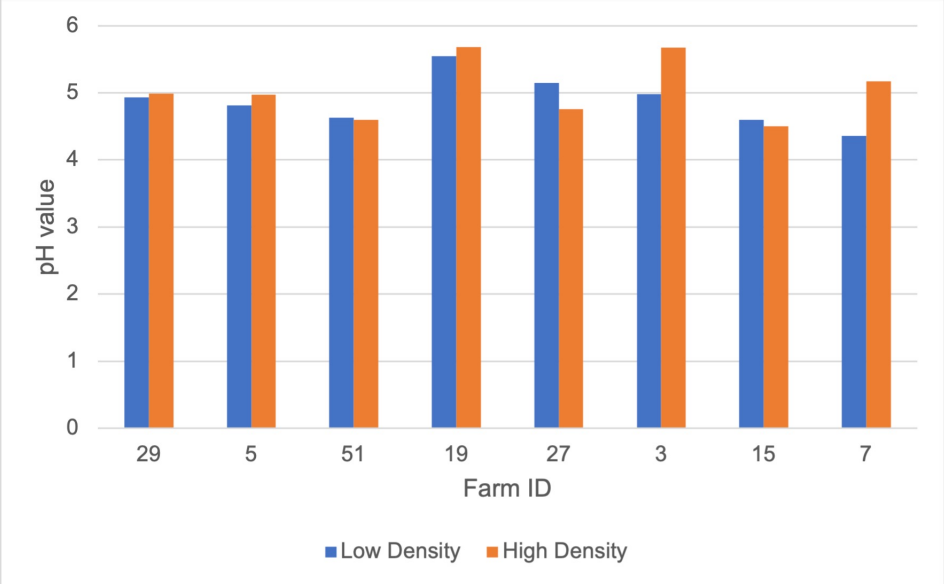



**Figure 10:** Soil pH values from different farms in Gikirima. Each farm shows two pH values, as one soil sample was taken on a plot with low-tree-density (LD: blue) and one with a high-tree-density (HD: orange).


**Figure 11:** Soil sampling at farm 29, with an eucalyptus tree bordering the coffee farm. (photo: Yasmin B. Versi). *Modified*

We found that for seven out of the eight farms, where we did soil sampling and semi-structured interviews, all farms used manure, while six farms additionally used inorganic fertilizers. Two farms stood out with their way of fertilizing. The pH of farm 27, which only used manure, was found to have similar values as the others, with the LTD having a value of 5.2 and the HTD of 4.8. Possibly the LTD received more manure as it had more coffee stems on it, leading to a higher pH. Farm 19, which added ash of firewood into composted manure and applied it on coffee, had the highest pH values in both LTD and HTD, with 5.5 and 5.6, respectively. The two farms 15 and 51, which were located right next to each other, were found with the lowest pHs in both the LTD and HTD (except for the LTD of farm 7), the latter being slightly lower in both cases. This shows that location, fertilization, and manuring might be relevant when looking at the soil pH in this area. However, we were unable to find strong connections between pH values and agroforestry practices or specific tree species (Fig. 12).

We found the carbon content to be high in all soil samples, with the lowest value being 3.33 (farm 51) and highest 6.11 (farm 29), both in the LTD (Fig. 12). In half of the farms (29, 19, 27, and 15) the carbon content was found to be higher in the LTD compared to the HTD counterpart, whilst the other half (5, 51, 3, and 7) had higher carbon content in the HTD compared to the LTD. The two farms 29 and 19 particularly stood out with high carbon content in both soil samples (Fig.12). The neighbors of farm 29 had large eucalyptus trees bordering the farm (Fig. 11). This affected the farmer's coffee plants visibly negatively, but possibly the carbon content positively as there was an old eucalyptus tree in the plot. The farmer's well-manured soil around his coffee plants possibly led to high carbon values in the LTD. The HTD of farm 19 had four trees on it, which was higher than all the other HTD plots, except for on farm 7; while the LTD had no trees on it. The LTD being well-manured, as it

only had coffee stems on it, might explain the difference between it and the HTD. Farmer 19 was well educated through training and workshops by the Kibugu Coffee Association about agroforestry, particularly about shading, diversification, disease-resistant crops, microclimate, and carbon capture. This might further have had an influence on the outcome of his soil management, as he is also the farmer we found to have the highest overall pH. Low carbon values, compared to the other farms, were found on farm 51 and 15 (Fig. 12). We did not conduct a survey or SSI at farm 51. Farmer 15 was one of the youngest we interviewed, only having owned his farm for around four years. He was not part of membership, as he did not have enough coffee stems, and struggled with soil erosion. The LTD sample was taken lower down his sloped farm compared to the HTD. This together with the soil erosion, might explain the higher carbon content in it and the big difference of 0.93% to the HTD. We were again unable to find strong connections between carbon content and agroforestry practices. However, the amount and age of trees, the education and memberships, and environmental factors, such as soil erosion, might play a role.

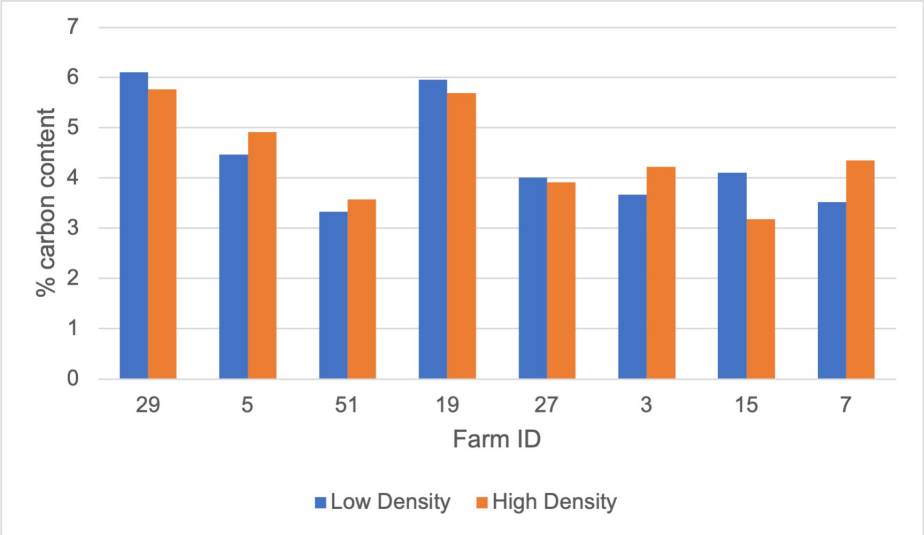



**Figure 12:** Soil carbon content from different farms in Gikirima. Each farm shows two soil carbon content values, as one soil sample was taken on a plot with low-tree-density (LD: blue) and one with a high-tree-density (HD: orange).

## 5.2 Institutions Shaping Agroforestry in Gikirima

As a second step, after gaining an overview of the farms in Gikirima, we wanted to understand the institutional context that may affect farmers' decisions concerning tree species and agroforestry practices on their farms. During our field research, we identified three major institutions that might affect smallholders' decision-making: Governmental agencies, the private sector, and social networks. These institutions can affect farmers' decisions through different means, e.g. by sharing knowledge and giving recommendations, impacting the availability of different tree seedlings, and the private sector also by influencing the demand for certain tree products. Influenced by these factors, farmers then make decisions specific to their respective circumstances and preferences. The presence of certain trees and agroforestry practices hence depends on a combination of socio-economic and environmental context and the individually perceived economic, environmental, and socio-cultural value of certain tree species and agroforestry practices.

In the following, the potential impact of institutions on agroforestry practices and tree species on farms in Gikirima is presented. The information gathered through our semi-structured interviews and survey data is used to outline observable consistencies and differences relevant to answering our research question. This section is structured along the influence mechanisms presented above: Institutions' perspectives on agroforestry, their means of influence, and their impact on the market for tree products. Subsequently, farmers' considerations when adopting agroforestry practices are contextualized within the institutional framework.

### 5.2.1 Institutions' Perspectives on Agroforestry

Our interviews provided insights into the perspectives of interviewees regarding agroforestry and their recommendations regarding tree species and agroforestry practices. A summary of the institutions we interviewed, along with their overall perspectives on agroforestry, is presented in Table 2. Except for the workers at the Gikirima Coffee Factory, all interviewees advocated for the promotion of agroforestry. The Agricultural Extension Officer, the Environmental and Climate Change Officer, and the representative of the tea factory emphasized the importance of agroforestry in mitigating climate change. Interviewees from LIMBUA and the cooperative society indicated that they promote agroforestry as long as it does not adversely affect the yields and quality of the products they are interested in (such as avocado, mango, macadamia, or coffee). In contrast, workers at the coffee factory stated that they cannot promote agroforestry because they aim to minimize shade for coffee cultivation. This point was confirmed by farmer 29, who mentioned that the coffee factory does not recommend planting trees. Regarding the persistent issue of land fragmentation in Gikirima, the Agricultural Extension Officer elaborated that practicing agroforestry becomes more challenging on smaller plots of land. He also mentioned that the government is in the process of developing a policy that would prohibit land fragmentation below one acre. Conversely, the Environmental and Climate Change Officer noted that the number of trees on farms may not be negatively impacted, as typically a tree boundary demarcation is done after land division. This tree boundary demarcation may partly explain our observed trend that smaller farms in Gikirima tend to show a higher tree density.

**Table 2:** Overview of institutions present in Kibugu, Embu county and their perspectives on agroforestry

| Institution | Description | Perspective on Agroforestry |
|---|---|---|
| Agricultural Extention Officer (SSI-1) | The link between farmers and the government. Expresses farmers' needs to relevant parties and presents new agricultural technologies to farmers. | Important to combat climate change, to local livelihoods, to conserve the natural forest and to enhance soil fertility and pH. |
| Environmental and Climate Change Department (SSI-2) | Enforces national and international environmental and climate actions. | Important to combat climate change, to conserve the natural forest and for soil conservation. |
| LIMBUA company (SSI-3) | A German-Kenyan company with over 7000 Kenyan smallholders that produces certified organic macadamia nuts, macadamia oil, avocado oil, and dried mango for export. | Encourages intercropping fruit trees in coffee plantations or planting cover crops underneath. Associated crops also need to be grown organically. |
| Kathangariri Tea Factory (SSI-4) | A tea processing factory belonging to the Kenya Tea Development Agency (KTDA), the umbrella company encompassing 54 tea companies in Kenya. | Encourages farmers to plant trees on at least 10-15% of their land to prevent climate change from seriously affecting tea production, and to provide firewood. |
| Kibugu Farmers Co-operative Society (SSI-5) | A coffee marketing society that encompasses five coffee factories in Embu County, which do the preliminary processing of coffee. | Intercropping coffee with trees is encouraged, but the shade factor of the incorporated trees needs to be below 30%. |
| Gikirima Coffee Factory (SSI-6) | A coffee processing factory belonging to the Kibugu Farmers Co-operative Society. | Cannot promote agroforestry since the aim is to minimize the shade for coffee. |

In terms of on-farm tree species, all institutions acknowledged the importance of additional income for smallholders, for which reason fruit trees constituted a main focus point of many institutions (SSI-1,-2,-3,-5). "Plant as many trees, which are directly beneficial to the farmers and also are mitigating the impact of the climatic change" (SSI-5), the agricultural extension officer stated. However, the tea factory representative explained that fruit trees are unsuitable for tea plantations due to the management plan required (pesticide spraying), which affects tea quality. On the other hand, intercropping fruit trees like avocado and macadamia with coffee was perceived as suitable by the manager of the cooperative society and the agricultural extension officer.

Furthermore, the extension officer and coffee factory workers named grevillea as being suitable for inter-

cropping with coffee, but the manager of the Kibugu Farmers Co-operative Society refrained from recommending grevillea on coffee farms due to disease harboring and competition with coffee. Farmer 19 contradicted this statement, mentioning that the Kibugu Coffee Society taught that grevillea is suitable since it doesn't affect coffee. According to the representative of the Kathangari Tea Factory, intercropping tea with grevillea is acceptable, given its easy pruning and slim canopy that minimally shades the tea underneath.

Eucalyptus is another species on which interviewees expressed different opinions. While the extension officer explained that his department discourages the planting of eucalyptus because of the high-water uptake, the climate change officer and the tea factory representative mentioned encouraging farmers to plant eucalyptus because of its fast growth and high firewood value. The Farmers Co-operative Society and the Gikirima Coffee Factory, on the other hand, discouraged planting eucalyptus due to its negative impact on soil fertility and water availability.

Indigenous tree species were emphasized by the agricultural extension officer for their carbon absorption capabilities. Meru oak was identified by the tea factory representative as suitable for tea plantations besides grevillea. The coffee factory workers also listed moringa as suitable for intercropping in coffee plantations. Farmer 9 confirmed being advised by an agriculturalist to intercrop mururi and moringa in coffee plantations due to their soil fertility-enhancing properties.

### 5.2.2 Institutions' Means of Influence

The ways institutions may exercise influence on farmers is through training, provision of seedlings and fertilizer, and governmental institutions also through policies. Based on the SSIs with representatives, the table 3 provides information on the extent and ways institutions may affect smallholders' farming systems in Gikirima. It shows that while agricultural extension services are demand-driven and the environmental and climate change department only reaches a limited number of people through infrequent one-day trainings (SSI-1, -2), the primary source of training for farmers comes from the private sector, particularly LIMBUA, and the coffee and tea factories. This is confirmed by farmers' statements. It is mentioned that there has never been an extension officer on the farm (Farmer 8, 19), with LIMBUA and the coffee factory emerging as the primary entities providing training (Farmer 7, 8, 9). Farmer 9 mentioned that LIMBUA conducts farm visits once every three months, while the coffee factory does so annually. Farmer 29 even indicated that LIMBUA visits monthly. Additionally, it's essential to recognize that group training may not be accessible to everyone. Farmer 13, for instance, cited mobility issues preventing attendance at training sessions, emphasizing instead the importance of social networks for acquiring knowledge on farming practices.

As indicated above, fruit trees are the primary seedlings given out to the farmer for free, by the government, as well as by the coffee factory (SSI-1, -6). Representatives from LIMBUA and the tea factory also stated to give out indigenous tree seedlings, which could, however, not be confirmed by our Interviews with farmers. In terms of fertilizer, all but LIMBUA sell subsidized inorganic fertilizer to farmers, but the agricultural officer and the manager of the cooperative society also mentioned the importance of organic fertilizer to conserve soil fertility. One farmer also told us the Coffee Factory gives out leftover shells from coffee beans as organic fertilizer.

In terms of policies concerning agroforestry, the Environmental and Climate Change officer told us about the

existing policy that obligates farmers to have a tree cover of at least 33 % on their farms, although its enforcement poses challenges. Furthermore, both governmental officers and the cooperative society manager highlighted the Rainforest Alliance and its policies regarding the implementation of agroforestry practices. The Rainforest Alliance is an international non-profit organization stating to "improve the livelihoods of farmers and forest communities, promote their human rights, and help them mitigate and adapt to the climate crisis" (Rainforest Alliance, 2024). It certifies the tea and coffee produced by factories in the area. Workers at the Gikirima Coffee Factory mentioned that Rainforest Alliance personnel visit farms, and the agricultural officer noted that the Rainforest Alliance actively promotes indigenous trees on farms. However, none of the farmers in Gikirima mentioned mentioned the Rainforest Alliance on their own accord in our interviews.

**Table 3:** Overview of training, seedlings and fertilizer provision by different institutions in Kibugu, Embu county.

| **Institution** | **Training** | **Seedlings** | **Fertilizer** |
|---|---|---|---|
| Agricultural Extension Officer (SSI-1) | Extension services by the government have been limited to demand-driven extension since 2018. | Tree nurseries were set up by a World Bank program. Seedlings are given out for free during the planting season. Commercial tree species, avocado and macadamia trees are emphasized. | Subsidizes inorganic fertilizers together with lime through the e-voucher program but stresses the importance of organic fertilizer. |
| Environmental and Climate Change Department (SSI-2) | Cooperates with the agricultural department. In every region, "champions" are selected which take part in one-day trainings and then share their knowledge within the community. | Currently lacks funding to be able to better promote agroforestry practices through giving out free seedlings and extension services. However, in cooperation with Farm Africa it aims to provide subsidized fruit tree seedlings. | |
| LIMBUA company (SSI-3) | Provides individual and group training; all members can always reach out in case help/advice with issues related to the trees relevant to LIMBUA is needed. | Tree seedlings of economic relevance to the company are sold for cheap, just to cover its running costs. They started to give away free indigenous tree seedlings to members. | Sells organic fertilizer to members. |
| Kathangariri Tea Factory (SSI-4) | Provides training which aims to improve tea production and share knowledge about other plants and trees beneficial to diversify farmers' income. | 20,000 exotic and indigenous tree seedlings were provided by the factory in 2023. | Sells subsidized NPK fertilizer to members. |
| Kibugu Farmers Co-operative Society (SSI-5)/Gikirima Coffee Factory (SSI-6) | Training is provided to members during factory meetings, focusing on sustainable coffee farming techniques. Agronomists additionally do individual farm visits. | In the past, Moringa (indigenous tree) seedlings were available for free, but this project was stopped because farmers were more interested in fruit trees. Now, along with coffee seedlings, the coffee factory aims to provide tree seedlings of interest to farmers. | Sells subsidized fertilizer to members. |

### 5.2.3 The Market for Tree Products

The market for tree products is another crucial variable to consider when discussing factors influencing farmers' decision-making. Among the institutions we interviewed, LIMBUA and the tea factory play significant roles in shaping the demand for tree products. LIMBUA purchases macadamia nuts, avocado, and mango fruits, while the tea factory officer expressed the need for timber (SSI-3, -4). Given that the tea processing in Kathangariri relies on firewood, the factory supplements its timber supply from eucalyptus plantations with timber from smallholders (SSI-4). Eucalyptus, being a fast-growing species with high calorific value, is prioritized by the Tea Factory (SSI-4). Furthermore, the Rainforest Alliance certification prohibits the use of indigenous trees as industrial firewood, the tea factory representative told us.

In addition to the market for tree products, the agricultural officer mentioned carbon-buying programs. According to him, farmers receive higher payments for indigenous trees, such as Murika, compared to commercial trees. However, neither farmers in Gikirima nor the workers at Gikirima Coffee factory mentioned carbon-buying programs during our interviews.

### 5.2.4 Farmers Considerations: The Influence of Institutions on Farmers

As presented above, the institutions we focused on provided diverse perspectives and visions on agroforestry development in Gikirima. It is visible that through multiple means they reach smallholders to different extents, thus influencing farmers' decision-making to varying degrees. This subsection focuses on of how the impacts of institutions manifest on farms, drawing upon our household survey and interviews.

Although governmental institutions and a tea factory officer emphasized the significant role of agroforestry in mitigating climate change, it appears that this aspect is not a major consideration for farmers when adopting agroforestry practices. Only one farmer mentioned climate change when asked about the environmental impact of their trees. However, according to the environmental and climate change officer, the Participatory Risk Climate Change Assessment (PRCCA) found that all farmers are aware of climate change and its impacts. But the absence of training initiatives by the government for farmers may have resulted in the ineffective communication of the role of trees and agroforestry as a strategy for mitigating climate change.

Furthermore, the differences in recommendations from the cooperative society and coffee factory concerning the suitability of intercropping coffee with grevillea can also be found on the farms. Smallholders expressed diverse perceptions regarding the impact of grevillea, and over 20% of farmers mentioned that the coffee factory supplied them with grevillea seedlings (Fig. 13). Additionally, farmers widely implemented the recommendation from the tea factory to intercrop grevillea with tea. On the other hand, while farmers told us that the coffee factory and government had discouraged them to plant eucalyptus (farm 9 & 13), many farms still contain eucalyptus trees. The tea factory's high demand for firewood may contribute to this phenomenon. In contrast, indigenous trees, though perceived as suitable for intercropping in coffee and tea by several interviewees and provided as seedlings by various institutions, are scarcely found on farms. This discrepancy could stem from institutions not effectively promoting indigenous species as they claim, and/or farmers not perceiving indigenous trees as beneficial compared to fruit or exotic timber trees.

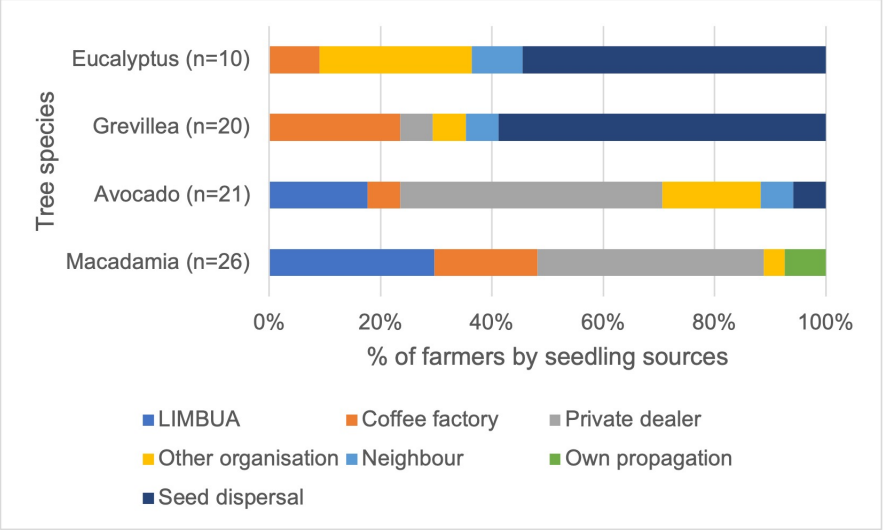



**Figure 13:** The seedling sources for tree species on the farms in Gikirima.

With a look on the influence of institutions through the provision of seedlings and fertilizer it can be stated that, according to Gikirima's farmers, LIMBUA and the coffee factory together provided around 50% and 25% of all the seedlings for macadamia and avocado, respectively, but 40-50% of the avocado and macadamia trees on farms in Gikirima were still bought from other private dealers (Fig. 13). The exotic timber trees show a different picture: Eucalyptus and grevillea were mainly gained through seed dispersal (more than 50%). Social networks only seem to play a subordinate role (10% or less). Moreover, the subsidized fertilizers sold by the different institutions seem to reach the farmers. 76% of farmers bought inorganic fertilizer through either the Coffee or Tea Factory and 24% of them bought fertilizers from both factories.

# 6 Discussion

## 6.1 Limitations and Reflections

In order to adequately discuss our results, it is important to reflect on the circumstances of our data collection, including its weaknesses. Throughout our fieldwork, we identified several problematic aspects in our data collection and continuously contemplated ideas for improvements. This chapter briefly outlines the limitations of our research, providing context for the presented data and narratives.

During our survey, we occasionally drifted from our original question sequence to minimize disruption. This led to questions being skipped and difficulties in attributing responses to the right questions. Additionally, due to lack of valuable feedback on certain topics (e.g. about the impact of different trees on biodiversity and soil parameters for individual trees) and to the survey being perceived too long, not all questions were consistently asked, resulting in missing data. A longer trial period with adjustments could have resolved these issues. Furthermore, we divided our group into two, in order to do more work. This had its benefits and drawbacks, as it led to more surveys being completed but also to an inconsistency in sampling methods.

Secondly, we recognize a shortcoming in our survey regarding farmers' perceptions of trees in mitigating climate change and the value they place on indigenous tree species. More specific questions on these topics would have provided deeper insights into local farmers' knowledge and priorities, influencing their decision-making processes. The limited data collected in this area limited our ability to analyze and discuss these aspects comprehensively.

Moreover, during our analysis, we recognized the potential benefits of incorporating additional data on socioeconomic variables that could influence the adoption of agroforestry practices. Including different livelihood assets as an additional part of the survey would have enabled us to better analyze whether differences in agroforestry adoption exist based on socioeconomic parameters.

Concerning our planned methods, we have to acknowledge that the mapping process of farms presented more challenges and consumed more time than anticipated. Our intention was to categorize farms based on specific characteristics recorded in our maps, but due to time constraints, we withheld from carrying it out.

Furthermore, additional interviews with a representative from the Rainforest Alliance and the Community Forest Association would have provided a clearer picture of the institutional context. In our SSIs, respondents often mentioned the Rainforest Alliance regarding the promotion of agroforestry. However, its exact role remains uncertain. The Community Forest Association, mentioned by some farmers for providing free tree seedlings, would also have been relevant for our research.

In reflecting on our group work, we acknowledge several challenges and learning experiences. As a large group of seven people, it was challenging to maintain clarity on tasks and decisions, leading to occasional miscommunications. Additionally, dealing with academic and cultural differences among group members posed another challenge, as well as the diverse teaching styles and personal work processes from our respective universities. However, these differences also provided valuable insights and opportunities to explore new research practices. Despite these challenges, we established a positive group dynamic and learned the importance of taking time to get to know each other for a better research cooperation.

## 6.2 Discussion of Results

In this section, we discuss our results in relation to our research questions and place them within the broader context of existing scientific literature. Firstly, our results show that agroforestry, in its simplest definition as having trees and crops and/or livestock on the same farm, was the prevalent farming system in Gikirima. Although variations within farmers' agroforestry systems existed, it was visible that farmers predominantly grew fruit as well as fast-growing timber trees as tree species on their farms (Fig. 5). Most farmers practiced intercropping, which contrasts from other studies conducted in similar environments in Kenya. These studies found that trees are mainly included as boundary trees due to farmers' concern about their impact on crops (Thorlakson and Neufeldt, 2012; Takaoka, 2008). However, specifically intercropping grevillea and coffee, as well as the controversy whether it is

beneficial for coffee production and the soil, is not unique to Gikirima (Sebuliba et al., 2022; Carsan et al., 2013).

We did not clearly observe the suggested effects of intercropping trees on the soil pH and carbon content. Generally, our findings suggest acidic soils with a high carbon content, without clear changes according to tree densities. The low pH may be explained by the fact that farmers often mulched with litter from grevillea, as it has been suggested that the slow decomposition rate of grevillea litter may contribute to soil acidity (Musongora et al., 2023). In addition, Nesper et al. (2019) reported that, due to grevillea's low litterfall, the carbon content in coffee fields are decreasing when grevillea is intercropped, whereas a higher carbon content is observed with native species (Nesper et al., 2019). In half of our cases, we did observe a lower carbon content with higher density of trees, suggesting factors beyond those identified in previous studies. In Gikirima, farmers often pruned trees and used the trimmings as mulch, which may contribute to this phenomenon. Furthermore, high carbon content in our plots could be attributed to mulching with leaves from avocado and mango trees.

Besides the effects of trees on soil parameters, tree products were an important supplement to the other cash crops coffee and tea, leading to diversified income and enhanced food security. Fruit trees often bear fruits outside the crop harvest season, while timber trees can flexibly be converted into additional income if needed (Mbow et al., 2014). As a result, they reduce the sensitivity to external environmental and socioeconomic shocks (Ibid.). This is especially valuable for farmers with smaller farms since they are more vulnerable to such shocks than larger farms. This might further explain our finding that smaller farms tended to have higher tree densities, along with the fact that trees are planted as a boundary after dividing farms for the next generation, as described by the environmental and climate change officer.

Moreover, climate change and biodiversity aspects seemed to only play a subordinate role in farmers' decision-making process since it was only mentioned by one farmer in our survey. However, it needs to be stressed that no direct questions were asked to clearly understand farmers' perception concerning these environmental factors. On the other side, the governmental representatives highlighted the role of agroforestry to combat climate change and the significance of indigenous trees in enhanced carbon sequestration. Muigai (2023) and Omoro et al. (2013) support the statement by the agricultural extension officer. They found that indigenous forests in Kenya sequestered more carbon than exotic tree species (Muigai et al., 2023; Omoro L. M. A. et al., 2013). Based on our household survey, however, it seemed that indigenous trees were only scarcely present on farms compared to exotic timber and fruit trees. This matches with the observations by (Reppin et al., 2020) in western Kenya, and might be linked to the provision of seedlings, the available market for fruit products from the private sector, and to farmers' need to maximize the economic output on the small farms in Gikirima.

However, the limitations of our research also need to be taken into consideration. While barely any farmer mentioned having indigenous trees on their farm, we sometimes did encounter indigenous trees (mainly moringa) during our farm visits. This finding suggests that indigenous trees may possibly perceived as less important by the farmer, and thus often remained unmentioned in the survey.

Furthermore, farmers may be discouraged to plant indigenous trees as, as stated by the tea factory representative, Rainforest Alliance certification prohibits the cutting down of indigenous species for the tea factory's industrial firewood needs. Without economic incentives such as Payment for Environmental Services schemes (PES-schemes), indigenous trees hence only have limited direct economic or practical value for farmers, compared to exotic species. A similar point is also expressed by (De Giusti et al., 2019), who suggest that it is necessary for smallholders to first of all have enough short term benefits from the adoption of agroforestry as a climate change mitigation practice to allow long-term mitigation benefits to happen. Nevertheless, (Leakey, 1993) find that farmers can benefit from indigenous species because, besides being more valuable for conserving native flora and fauna, they are better adapted to the environment and therefore less susceptible to pests and diseases. Relying on a few exotic timber and fruit tree species might therefore be risky, especially considering the anticipated impacts related to climate change. One possibility to counteract this reliance on exotic species would be to partly substitute them with suitable indigenous multipurpose/timber/fruit tree species and support the marketing for their products. (Kehlenbeck K et al., 2013) show, for example, that indigenous fruit tree species in Kenya have a high potential to substantially improve the livelihoods and health of farmers and consumers.

Moreover, it is questionable whether the increased influence of the private sector will lead to sustainable farming systems that are beneficial for farmers and the environment. As private companies, first of all, concentrate on their own profit maximization, the idea that the existing influence structures also lead to the best outcome for farmers and the environment is doubtful. A statement published by the Kibugu Farmers Co-operative Society validates this doubt. It mentions that "With washed coffees working so well, you won't find many manager willing to mess around with [...] certifications like organic" (Kibugu FCS, 2022), and states the following challenges for its factories: "How do cooperatives [...] keep their members engaged in coffee? How do we take away red tape to encourage more farmers to plant more coffee, as opposed to corn or dairy?" (Kibugu FCS, 2022). It is to be expected that also other private actors, such as the tea factory and LIMBUA, have a similar agenda, which is trying to influence smallholders' farming systems in a way that suits the company's interests, and not in the interest of farmers and the environment.

However, while private companies prioritize their own interests, their effects on local livelihoods and the environment does not necessarily have to be negative. By providing farmers the opportunity to participate int the global market for fruit tree products, such as macadamia nuts, avocado and mango fruits, LIMBUA, for example, facilitates the growth of trees, which has positive effects on soil conservation, mitigating climate change, and reaching the Kenyan 10% tree cover goal, and also pays a higher-than-average price, benefiting local livelihoods. Additionally, private institutions could also cooperate to create systems that are of interest to multiple actors and, with it, facilitate more diverse and profitable agroforestry systems. As the manager of the Kibugu Co-operative society mentioned, fruit trees like avocado and macadamia can be intercropped without compromising coffee yields if adequate management practices are implemented. However, (Mithamo M. W., 2013) find that fruit trees generally depress coffee yields, while they have positive effects on the soil fertility and coffee quality. But also intercropping

fruit trees in tea plantation may be an option. Although the representative of the tea factory discourages farmer to intercrop tea with fruit trees, (Duan et al., 2024) has found that intercropping fruit trees in tea plantations has the potential to enhance soil characteristics and tea quality.

Nevertheless, also the risks and problematic aspects connected to powerful export-oriented institutions should not be neglected. The argument by Bibi-Farouk (2023), which is directed by the fact that Africa as a continent is a net importer of agricultural products, can also be translated to the agricultural export market system (Bibi-Farouk, 2023). Facilitating an export-oriented agricultural system (according to (Bibi-Farouk, 2023)), being dependent on agricultural imports) likely results in the loss of traditional farming knowledge and methods (Ibid.). This in turn reduces farmers' capacity to produce enough, diverse, and nutritious food, making them more vulnerable to the impacts of climate change. Hence, the risk of food poverty is elevated (Ibid.). Based on these arguments, limiting extension services almost exclusively to the private sector, can be seen critically. The increased power of private companies likely leads to biased knowledge transfer influencing farmers' decision-making and non-economic aspects being undervalued.

However, even though our results show that farmers in Gikirima are, in terms of species grown and extension services received, visibly impacted by the institutional context, they are not fully controlled by the private sector. No farmer solely grew cash crops, but all considered subsistence needs, such as firewood, timber, and diversified farms through combining a variety of crops, trees and livestock. Furthermore, the tree seedlings bought/received by farmers came from a variety of sources and not exclusively from the major private corporations we interviewed, and farmers also made decisions concerning their farming system based on own observations, experiences, and probably also based on convenience (50% of the exotic timber trees on farms in Gikirima were naturally introduced through seed dispersal). In addition, according to our survey, the impact of trees on soil and crops did not always seem linear and depended on additional variables. Tree pruning, fertilization, and spacing may be variables affecting different agroforestry practices to succeed, as explained by various farmers in Gikirima, and confirmed in the literature (Nurcholis et al., 2024). In this regard, also reinforced farmer-to-farmer knowledge exchange may preserve already existing local knowledge. Nevertheless, farmers have to navigate within the institutional context, which limits the existing options and alternatives. In terms of cash income, the existing market is the main variable farmers need to consider, which is currently predominately export-oriented. Governmental programs and policies, the private sector, and the farmers themselves will further shape these present farming systems and will decide the role agroforestry plays in smallholder farming systems when facing the challenges of climate change mitigation, food security, and sustainable livelihoods.

# 7 Conclusion

Our research aimed to understand the agroforestry practices present in Gikirima (Kenya), how institutions influence the adoption of agroforestry practices, and how these practices affect environmental and socio-economic variables. We encountered a diversity of food and cash crops, fodder, fruit, macadamia, and timber trees in several different spatial arrangements, often along the presence of livestock. All these systems consider subsistence and income needs, with different species either contributing to solely one of these needs, or are utilized for both. We found that especially the private sector has a great influence on the adoption of agroforestry practices in Gikirima, primarily since it is mainly private companies that provide extension services, while governmental extension services are only provided on demand. The predominant fruit trees found on the farms correlate with the products LIMBUA, a German-Kenyan company, buys and exports: Macadamia and Avocado. Furthermore, fast-growing exotic timber species were dominating over indigenous timber tree species, which is also influenced by the institutional context, as well as by farmers' own perceptions.

With our findings we can show that the institutional context is a main factor shaping the adoption of agroforestry practices and should therefore be a central focus when analysing agroforestry development. By reducing the governmental influence on farmers through extension services, the power increasingly shifts toward the private sector. This development can be discussed critically, as it potentially results in landscape changes driven by the economic interests of private companies, which could pose increase environmental and socio-economic risks for local communities. Nevertheless, our findings indicate that while a shift towards corporate farming is apparent, farmers continue to make decisions based on their own perceptions and priorities, and are not (yet) entirely dominated by the private sector.

These findings imply that future development is highly dependent on the incentives provided by different actors (government, NGOs, and private sector). The government and NGOs have the opportunity to influence development by offering extension services that address environmental and livelihood aspects, which may not be addressed in the training provided by the private sector. Private companies, on the other hand, could cooperate to enable more diverse systems. However, expecting the private sector to be the leading force in facilitating systems that prioritize local livelihoods and the environment seems irrational. In order to support change towards sustainable and resilience agroforestry systems, additional policies, incentives (e.g. Payment for Environmental Services schemes) and support programs are necessary. Additionally, further research into agroforestry systems suitable for this region is essential, including research on indigenous multipurpose/fruit/timber trees. This research output, coupled with subsequent support programs, could play a crucial role in establishing diverse, profitable, sustainable, and resilient agroforestry systems that yield optimal outcomes for communities, the environment, and the economy alike.

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# A Appendix

## Appendix I: Overview of Applied Methods

| **Method** | **Details** |
|---|---|
| Preliminary Survey | Six respondents |
| General Survey | 29 respondents |
| Semi-Structured Interviews | Total of five interviews with governmental and company officials: Agricultural extension officer of Embu County, LIMBUA, Kibugu Farmers Co-operative Society, Gikirima Coffee Factory, and Kathangariri Tea Factor |
| Key Informant Interview | One interview with the Elder of Gikirima |
| Soil samples for pH and carbon content (analyzed in lab at Copenhagen University | Eight participants |

## Appendix II: Semi-Structured Interviews

Semi-Structured Interview 1 (SSI-1): Agricultural Extension Officer

**General Questions:**

1. What is the role of an agricultural officer?
2. How long have you been an agricultural officer?
3. How does the agriculture department understand agroforestry practices (definition)?
4. Do you promote agroforestry practices?
5. How does the agriculture department promote agroforestry practices (specifically for smallholder farmers)?
6. What challenges are you facing when promoting agroforestry practices? What are possible resolutions for that?
7. What is the role of an extention officer?
8. Do they offer training? What kind of training?
9. Do they do follow-ups on the farms? (ask farmers for feedback on how their AF farm is going)
10. If yes, what kind of feedback have extension officers received from farmers regarding AF?
11. Are you promoting farmers to plant specific tree species in Embu county/Kibugu?
12. Which aspects do you consider when promoting specific trees? e.g soil erosion, nutrients, water, windbreaker etc.

13. Which crops do you promote with what trees?
14. What kind of subsidies are offered to farmers? (farming inputs: fertilizer, seedlings...)
15. Is the government promoting organic farming?
16. Land acres are getting smaller through splitting of the land. This makes farming, especially AF farming harder - what measures are taken to solve this?
17. There are various benefits from agroforestry - socio-economic, and environmental: What measures are you taking to educate farmers about the environmental ones?
18. What are the county's future plans concerning agroforestry?
19. What is the agriculture department's perception of eucalyptus?
20. Do you promote eucalyptus?
21. Have you done any (scientific) research on eucalyptus (have you found out the pros and cons)?
22. Many farmers are (have been advised to) cutting their eucalyptus - why do you think farmers are cutting their eucalyptus? And do you condone their choices?
23. Does the agricultural department and private crop organizations (coffee, tea, macadamia, avocado organizations/companies/) collaborate?
24. What is their role in preventing private companies from exploiting smallholder farmers?
25. Which aspects of the Kenya Vision 2030 are you promoting in Embu county/Kibugu area?
26. Are you promoting the goal of a 10% tree cover on farms? If yes, how?

Semi-Structured Interview 2 (SSI-2): Environmental and Climate Change Department

**General Questions:**

1. What is the role of an environmental and climate change officer?
2. Do you promote Agroforestry practices?
3. Are there ongoing programs that support agroforestry?
4. What challenges are you facing when promoting agroforestry practices? What are possible resolutions for that?
5. What are the County's future plans concerning agroforestry?
6. There are various benefits from agroforestry - socio-economic, and environmental: What measures are you taking to educate farmers about the environmental ones?

7. What type of tree species does the county recommend for agroforestry in small-scale farms?
8. Are local smallholders aware of climate change?

**Eucalyptus**:

1. What is your perception of eucalyptus?
2. Do you promote eucalyptus?
3. Have you done any (scientific) research on eucalyptus (have you found out the pros and cons)?

**Government Support:**

1. What are the government facilities that you provide to small scale farmers?
2. Does your department provide fertilizers? What type of fertilizers?
3. Does your department provide training?
4. What measures are in place to counter the exploitation of farmers by the private sector?
5. Land acres are getting smaller through land subdivision. This makes farming, especially AF farming harder - what measures are taken to solve this?

Semi-Structured Interview 3 (SSI-3): LIMBUA Company

**General Questions:**

1. Does LIMBUA promote agroforestry on their members' farms?
2. Does LIMBUA encourage the planting of shade-tolerant crops under the trees? Which ones?
3. Are there any problems with pests & diseases? If yes, how do you deal with them?
4. Does LIMBUA promote fruit trees as shade trees for coffee?
5. Does LIMBUA provide training on regenerative farming techniques?

Semi-Structured Interview 4 (SSI-4): Kathangariri Tea Factory

**General Questions**:

1. Does KTDA promote agroforestry?
2. Do you encourage farmers to intercrop trees on their tea farms?
3. Which tree species do you use for tea processing?
4. Have they ever thought of using any other form of energy in their process?

5. How does climate change affect tea production and how does KTDA deal with it?
6. Do you provide seedlings and training to small scale farmers?

Semi-Structured Interview 5 (SSI-5): Kibugu Farmers Co-operative Society

**General Questions:**

1. What does the Co-operative Society do?
2. Do you promote Agroforestry? How?
3. Which tree species do you promote? Why? Do you promote a certain type of intercropping with trees?
4. Which benefits do you provide for farmers? Seedlings/training/fertilizer? Does every farmer in Gikirima have access to the services provided by you?
5. Do you feel the impact of climate change on coffee and which adaptation strategies do you have?

Semi-Structured Interview 6 (SSI-6):Gikirima Coffee Factory

**General Questions:**

1. How long has the factory been here?
2. How many farmers bring coffee here?
3. What is the process of registration?
4. How much coffee do you get annually?
5. What do you advise farmers? Concerning fertilizer use and how to plant?
6. Is all coffee accepted?
7. Is there a certification scheme?
8. Do you have a Rainforest Alliance certification?
9. What is your stance on intercropping with trees? What do you recommend? Which trees do you recommend?
10. What is your opinion on intercropping with macadamia and avocado?
11. Do you conduct follow-ups on farms?
12. Do you provide training?
13. What does the NAGRIB workshop provide?
14. What is your climate plan?

15. How do you support farmers to meet the goal of 10% tree cover on farms?

16. Do you receive any governmental support?

17. Where do you obtain your seedlings?

# Appendix III: Synopsis

## Coffee Agroforestry Practices in Gikirima, Kenya

Synopsis

23rd February 2024

University of Copenhagen
SLUSE: Practicing Interdisciplinary Field Research on the Environment

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KØBENHAVNS UNIVERSITET

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**Introduction & Background**

Climate change, food security, and sustainable livelihoods are found to be three main challenges sub-Saharan Africa (SSA) is currently facing and is expected to face in the future. These challenges are found to be interconnected and therefore need to be understood as such. For instance, communities and farmers dependent on rain-fed agriculture are vulnerable to climatic shifts in the water cycle, which poses considerable pressure on their livelihoods (Connolly-Boutin and Smit 2016). In SSA farmers with holdings smaller than two hectares make up around 80% of agriculture and are known as smallholder farmers (Lowder et al. 2016). Smallholders are especially vulnerable to the aforementioned challenges. Therefore, to combat the adverse effects climate change has on agricultural production, some farmers are now using an increased amount of agricultural inputs, such as mineral fertilizers, pesticides, insecticides, and herbicides. While some of these practices may be beneficial in the short run, they are often found to be unsustainable in the long run (Awazi and Tchamba 2018). Hence, to ensure long-term productivity, systems that include "sustainable, productive, pro-poor and climate-smart practices" (Awazi and Tchamba 2018) are needed.

Ayantunde et al. (2018) define sustainable agriculture as "agriculture that is sufficiently productive to meet food needs in both short and long-term, and that is economically viable, environmentally friendly and socially acceptable". One practice that can fall within sustainable agriculture is agroforestry. Agroforestry systems vary widely in their execution, but they all include the incorporation of woody perennials in crops or pastures for environmental, climatic, economic, and/or sociocultural benefits (Mbow et al. 2014). Studies have found that agroforestry practices can, among other things, combat deforestation, desertification, erosion and decreasing soil fertility, while at the same time providing food, fuelwood, timber, and other ecosystem services (Shidiki et al. 2020). Soil fertility, for example, benefits from agroforestry practices, as runoff and soil erosion can be controlled and fewer organic materials and nutrients are lost. Further, the soil organic matter content can be enhanced through litter fall and fine-root turnover (Syano et al. 2023). However, it needs to be pointed out that there are also possible trade-offs in agroforestry systems. Low available phosphate and soil moisture content can, for example, result in severe competition for water and nutrient resources. Here, the selection of woody perennial species, placement and management are essential to minimize any negative effects (Kuyah et al. 2019).

Agroforestry practices make up large parts of smallholder agricultural systems in SSA (Mbow et al. 2014). Around 29% of agricultural land in SSA is connected to agroforestry practices (Wanjira and Muriuki, 2020). This, however, is not new to the region - for thousands of years farmers in SSA have been practicing what is today defined as agroforestry (Cook and Grut 1989). In Kenya there are three main agroforestry systems: agrosilvicultural, silvipastoral and agrosilviculture. Within these systems, there are the following major agroforestry practices (AfPs) relating to the placement of the woody perennials: mixed farming, dispersed trees in croplands, home gardens, trees along hedges, farm boundaries, woodlots and home compounds (Mugure and Oino 2013).

**Agroforestry in coffee plantations**

Coffee is one of Kenya's most important export cash crops. It makes up around 22% of the national income and more than 700,000 households structure their livelihood around coffee farming (Wanzala et al. 2022; Hyde 2009). Coffee (Coffea arabica L.) is grown in 32 out of 47 counties and is mainly exported to the USA, Belgium, Sweden and Germany (Othuon et al. 2021; Piikki et al. 2016). Wild coffee grows as an understory tree and until the 1970's coffee production likewise primarily took place with the use of shade trees. Shade trees protect the coffee crop against microclimate variability and reduce high solar radiation while offering the other benefits associated with agroforestry systems, such as improved soil fertility and reduced soil erosion (Jaramillo et al., 2013).

**History of Coffee Production in Kenya**

Coffee was first introduced to Kenya in 1893 by the British colonizing power which aimed to establish a capitalist economy with the introduction of cash crop production, such as coffee, and by developing an export market. Later on, western agricultural technologies such as fungicides, pesticides and inorganic fertilizers were introduced in order to boost production (Wanzala et al. 2022). Coffee was first grown on European-owned estates and plantations, with Kenyans being restricted from coffee production until 1929 (Wanzala et al. 2022). In the period between the 1930s and up until the independence in 1963, Kenyans were permitted to own small acreages for coffee production, subjected to a list of constraints and laws which granted white settlers authority over the plantations (Wanzala et al. 2022; Hyde 2009). Following Kenya's independence, coffee remained a valuable cash crop for the country's economy (Wanzala et al. 2022). Due to this, the government chose to invest in coffee production focusing on expanding selection and improving coffee quality (Wanzala et al., 2022). Nevertheless, the coffee industry faced challenges, such as the fluctuating global coffee prices, which impacted Kenyan coffee farmers' production and income, and has led to a production decline of around 50% over the last three decades (Carson 2013; Othuon et al. 2021: Wanzala et al. 2022). To revitalize the coffee industry, the Kenyan government has implemented various initiatives over the last 10 years, e.g. targeting more effective processing, new coffee exchange regulations, and increased marketing of Kenyan coffee (Othuon et al., 2021).

**Study Site**

Embu is a central county in Kenya which has a high production of coffee (Othuon et al. 2021). Other than coffee, the main cash crops in the area are tea and macadamia, and the main food crops are beans, potatoes, maize, and bananas (Njeru, 2020). Embu County has been a coffee producer since colonial times due to its optimal environmental conditions in especially the highland portions of the county, namely in the North, West and East. Embu County is located at an altitude between 1520-1820 meters above sea level. The county is characterized by an average annual temperature of 20°C and experiences two rainy seasons: occurring from March to July, and September to December. The annual precipitation is 1400-1700 mm. Due to the area's humic nitisols, the soil has moderate to high soil fertility (Othuon et al. 2021). The average size of farms in the area is less than one hectare due to land fragmentation (Piikki et al. 2016).

Coffee farming covers the largest area of Embu County, with a production of around 800 kg of clean coffee

per ha (Othuon et al. 2021). Until the 1970s, coffee was mainly grown in shade but in order to enhance productivity, sun-resistant varieties were introduced which led to the gradual decline of shade trees on coffee plantations (Jaramillo et al. 2013). However, the reintroduction of shade trees has become an adaptation strategy to challenges such as rising temperatures, biodiversity loss, declining soil fertility, combating pests and diseases, and soil erosion (Jaramillo et al. 2013; Tamubula & Sinden 2000). Coffee agroforestry with shade trees has shown to change the microclimate, increase soil water availability, reduce high solar radiation, improve soil fertility, protect against pests, and have economic benefits for farmers, as they can also produce timber, fruit, medicines and/or fodder (Jaramillo et al. 2013; Carson et al. 2013). In Embu County most cropping systems contain planted and remnant trees in boundary line planting and within coffee plots (Carson et al. 2013).

**Farmers' choice of trees on farms**

Two commonly planted tree species are the introduced *Grevillea robusta* and *Eucalyptus sp.*. *Grevillea robusta* was introduced to Kenya in the late 19th century for use as a shade tree in tea, coffee and cinchona plantations whereas Eucalyptus was introduced in 1902 to supply fuelwood for the Kenya-Uganda railway. Today both trees are grown for a variety of products including fuelwood, timber, transmission poles etc.. They are fast-growing species with good economic returns (Muchiri et al. 2004; Oballa et al. 2010). According to Oballa et al. (2010), the area under eucalyptus is likely to increase because of high demand for the products it supplies.

However, both of these exotic species have their drawbacks. For eucalyptus, concerns have been voiced over the adverse effects of growing the species near water because of the drying of streams, springs and rivers as well as concerns about it negatively affecting biodiversity and soil fertility (Oballa et al. 2010). Grevillea robusta reduces the aboveground biomass and yield of maize, and farmers therefore prune Grevillea trees to manipulate the resource competition between the species. There has also been increasing conflict between neighbouring farms because unmanaged stands of Grevillea on farm boundaries can reduce the crop yield and tree growth on adjacent farms (Muchiri et al. 2004).

As already mentioned, Eucalyptus sp. and *Grevillea robusta* are common in the Kenyan landscape despite their drawbacks. Indigenous tree species, on the other hand, are less frequent in coffee plantations due to insufficient planting materials and the perception that indigenous species are slow-growing (Carsan et al. 2013).

Kenya's colonial history, the introduction of coffee production and of exotic species have all affected the landscape composition of this region. Since 80% of farmers in SSA are smallholder farmers, the future prospects of the Kenyan landscape depend on a variety of factors ranging from farmers' individual perceptions, their beliefs, wants and needs, but also the historical context and institutional framework their farms are placed within. Smallholder farmers are limited by poor access to agricultural credit, therefore they mostly use family labour and are constrained by high production costs of inputs (Wanzala et al. 2022). They are also constrained by institutional factors such as access to seedlings, improved seedling varieties and whether there is a ready market for their products

(Oballa et al. 2010; Wanzala et al. 2022). Therefore the purpose of this report is to research the rationalizations and impacts of agroforestry management practices in our case study area Gikirima, Embu County, Kenya. Hence, we propose the following research question:

*What factors influence smallholders' choice of agroforestry practices (AfP) on coffee farms in Gikirima, Kenya, and what impact do the selected management practices have on environmental and socio-economic variables?*

This will be done by answering three sub-questions:

1. Which agroforestry practices are present on coffee farms?
2. What incentivizes and hinders farmers to choose specific AfP on coffee farms, and what influence does the institutional framework have?
3. What impacts do the different AfP on coffee farms have on environmental and socio-economic variables?

**Methodology**

In the following part, we outline the research methods we plan to use for gathering the data to discuss our selected research questions. We aim to use five different methods, which will be presented in the order we plan on carrying them out. Additionally, the sub- and sub-sub questions each method is designed for will be presented (see Appendix I, data matrix for more details).

**Method: General Survey**

With the help of key informants we will identify coffee farms in Gikirima, Kenya. On these farms, we will conduct a general survey to get an overview of the different coffee farming systems present. The survey will include questions about the farmer and farm (e.g. size of the farm), the agroforestry systems (data for research questions (RQ) 1.1), and management practices (incl. pruning, mulching, chemical and organic fertilizer, pest control, and liming) that are present (data for RQ 1.2). Further, the survey will ask about coffee yields and additional income from tree products (e.g. firewood, timber, and fruit) (data for RQ 3.3). Based on these findings, we strive to stratify existing agroforestry coffee farms into three (to four) agroforestry categories, based on the presence, density, positioning, and variety of trees on the farm. However, we will make the final decision on-site to ensure a categorization that makes sense for our study site. The specific farms which will be used for all the following methods will be selected from the various strata using the randomized sampling method. To analyze our data, we will use descriptive statistics and if relevant statistical tests to e.g. explore correlations between AfP, soil parameters, and corresponding yield.

**Methods: Transect Walk Farm Mapping**

We will conduct transect walks with the farmers on the stratified sample farms to get an overview of the farms. During these, we will note the different characteristics, such as tree positioning, densities, species (if applicable),

and topography (data for RQ1.1). We will ask additional questions if they seem relevant (e.g. age of the trees) during the walk. With this information, we aim to draw a map of the farm that shows our interpretation of the farm layout. We might use remote sensing data to further enhance the precision of our farm map (data for RQ1.1). To analyze our recorded farm characteristics, we will use descriptive statistics.

**Method: Semi-Structured Interview**

Further, we will conduct a semi-structured interview. This will first concern the farmers' reasoning for incorporating trees on their coffee farms (data for RQ 2.1), then the farmers' reasoning for incorporating specific tree species (data for RQ2.2), and lastly the farmers' perceived impacts on environmental (e.g. pest and diseases, soil fertility, and climate change) and socio-economic (e.g. labour intensity, and economic output) variables (data for RQ3.1). We will be looking into factors which may have influenced the decision-making to plant trees and/or specific tree species (e.g. advertisement, availability, and price of seedlings, expected economic value of trees, and cultural reasons). We will transcribe and code answers with Nvivo and further identify and group by themes which we will place within a cultural, institutional, environmental, and socio-economic framework. We will triangulate data from the semi-structured interview with data collected by other methods.

**Method: Ranking**

Following the semi-structured interviews, we will ask agroforestry coffee farmers to rank different incentives for why they decided to intercrop with trees (data for RQ 2.1). These incentives will be identified from the semi-structured interview and we will leave space for alternative options. We suggest/expect incentives such as soil enhancement, biodiversity, climate change adaptation, pest and diseases, institutional incentives, economy, fuelwood, timber, and food. We will ask farmers to rank their incentives in terms of importance, with the definitions "don't know" "not important" "low importance" "moderate importance" and "high importance".

This data will be triangulated with a further ranking of the benefits of the different tree species planted on the farm in order to understand what determines their choices (data for RQ 2.2). For this ranking, farmers will be asked to rank their tree species within categories that will be determined from the semi-structured interviews. We expect categories such as fuelwood, edible, soil properties, economic value, construction, fodder, shade, and medicine. The ranking definitions will be "unknown", "good", "average", and "bad" or "unknown", "not useful", "moderately useful", "highly useful".

**Method: Soil Sampling**

We will collect soil samples in order to observe the effects different coffee AfP have on soil parameters (data for RQ 3.2). One homogenous soil mixture sample will be taken from each farm by collecting soil from five different spots on the farm using a soil sampler probe and a bulk density ring (core cutter). We will analyze the soil for bulk density, water-holding capacity, pH, soil organic carbon, soil organic matter, and nutrient content (available nitrogen and phosphorus). With the gained data, the effects of different coffee AfP on soil parameters will be compared. The data collected will be triangulated with the data obtained through our survey/semi-structured

interviews, in order to include the impacts different management approaches (additional fertilizer usage, tillage, etc.) can have on soil parameters.

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## Appendix I: Data Matrix

### Data Matrix

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Overall objective** | Assessing agroforestry coffee farms in Gikirima, Kibugu, Kenya. | | | | | | |
| **Overall research question** | What factors influence smallholders' choice of agroforestry practices (AfP) on coffee farms in Gikirima, Kenya, and what impact do the selected management practices have on environmental and socio-economic variables? | | | | | | |
| **Research Design** | **Duration of fieldwork:**<br>2 weeks<br>**Data Collection:**<br>One point in time | | **Research team size:**<br>4 students from University of Copenhagen<br>2 students from University of Nairobi<br>1 student from Wangari Maathai Institute for Peace and Environmental Studies | | **Field Site:** Gikirima, Kibugu, Embu County, Kenya | | |
| **Definitions** | **Agroforestry:** inclusion of intentional incorporation of woody perennials in crops or pastures for environmental, climatic, economic, and/or socio-cultural benefits | | | | | | |
| **Sub-questions** | **Sub-sub-questions** | **Data required: Variables** | **Data Collection Methods** | **Sampling strategy** | **Data Analysis Methods** | **Output** | **Limitations** |
| 1. Which AfP are present on coffee farms? | 1.1 What is the physical layout of the farms? | Size of farm, topography, tree species, age, densities, positioning, other | Survey,<br><br>Transect walk<br><br>(Participatory) mapping of farm | Stratified sample, 10-20 farms | Comparison of present coffee farming systems (possibly categorization of similar layouts), descriptive statistics | Farm layout<br><br>Visualization: Farm maps, table (size, number of species) | Categorization may be difficult (which similarities, which differences) |
| | 1.2 Which management practices are applied? | Pruning, mulching, chemical/organic fertilizer use, liming, pest control, other | Survey | Same farms as above | Descriptive statistics | Identifying present management practices | Categories for survey may be incomplete |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Visualization: Graph or table | |
| 2. What incentivizes farmers to choose specific AfP on coffee farms, and what influence does the institutional framework have? | 2.1. What impacts farmers' decision to incorporate trees on their coffee farms? | Variables encompassing cultural, institutional, environmental and socio-economic incentives and disincentives | Semi-structured interview, Ranking | Same farms as above | Descriptive statistics, Coding with NVivo | Understanding the rationalization of farming choices<br><br>Visualization: Graphs | Ranking: everybody has a different understanding of a scale.<br><br>Researchers biased interpretation |
| | 2.2. What impacts farmers' choice of tree species? | Variables encompassing cultural, institutional, environmental and socio-economic factors | Semi-structured interview<br><br>Ranking benefits of tree species | Same farms as above | Coding with NVivo | | |
| 3. What impacts do the different AfP on coffee farms have on environmental and socio-economic variables? | 3.1. How do farmers perceive the impact of their AfP on environmental and socio-economic variables? | Environmental: Pest and diseases,<br>Soil fertility,<br>Climate change adaptation,<br>Other<br><br>Socio-economic:<br>Labor intensity,<br>Economic output,<br>Other | Semi-structured interview | Same farms as above | Coding with NVivo | Perceived impacts of AfP | Researchers biased interpretation |

**Appendix II: General Survey**

Introduction

Thank you for participating in this survey. The purpose of this survey is to gather information about coffee farming practices, including the incorporation of agroforestry systems, in Gikirima, Kenya. All data collected will be handled confidentially and used only for research purposes. Your participation is voluntary, and you may choose not to answer any question. Thank you for your time and valuable insights.

General information (to trace back for in-depth interview):

1. Name of farmer:

2. Location of the farm (GPS coordinates if available):

Demographic Information:

1. Age:

- [ ] 18-25
- [ ] 26-35
- [ ] 36-45
- [ ] 46-55
- [ ] 56 and above

2. Gender:

- [ ] Male
- [ ] Female

3. Education level:

- [ ] No formal education
- [ ] Primary education
- [ ] Secondary education
- [ ] Vocational training
- [ ] Higher education

4. Household size*:
*(*the number of people permanently/primarily living in your household, including yourself)*

5. Occupation(s):

- [ ] Farmer
- [ ] Laborer

- [ ] Entrepreneur
- [ ] Professional
- [ ] Other (please specify) _____

6. Income sources (tick all that apply):
   - [ ] Coffee
   - [ ] Livestock
   - [ ] Other on-farm products
   - [ ] Off-farm employment
   - [ ] Other (please specify) _____

Farm management overview:

1. Size of the farm (in acres/hectares):
2. Topography of the farm:
   - [ ] Mostly flat
   - [ ] Mostly sloping
   - [ ] Mostly hilly
3. Are trees incorporated on the coffee farm? (Yes/No)

   If yes:

   3.1. Which tree species do you have?
   - [ ] Eucalyptus
   - [ ] Grevillea
   - [ ] Macadamia
   - [ ] Avocado
   - [ ] Other (please specify): _____

   3.2. How are the trees positioned? (Select all that apply)
   - [ ] Alley cropping
   - [ ] Boundary
   - [ ] Random, unstructured
   - [ ] Intercropped, structured
   - [ ] Other (please specify): _____

4. Are other crops incorporated on the coffee farm? (Yes/No)

   If yes, which ones? _____

5. What is the average age of coffee plants on the farm?

6. What estimated percentage of the coffee is shaded throughout the day?

7. Is your coffee farm irrigated? (Yes/No)

8.1 Which management practices are applied on the farm? (Select all that apply)

- [ ] Coffee pruning
- [ ] Shade tree pruning
- [ ] Mulching
- [ ] Use of chemical fertilizer
- [ ] Use of additional organic fertilizer*
- [ ] Use of herbicides
- [ ] Use of chemicals to control pests and diseases (e.g. pesticides, fungicides)
- [ ] Manual weeding
- [ ] Liming

(*from outside the coffee farm)

8.2 If applicable, how often are these management practices conducted? (Annually, Bi-annually, Quarterly, Monthly, Continuously):

Coffee pruning: _____

Shade tree pruning: _____

Mulching with on-farm debris: _____

Chemical fertilizer: _____

Additional organic fertilizer: _____

Herbicides: _____

Chemical pest and disease control: _____

Manual weeding: _____

Liming: _____

<u>Coffee yield and additional cash and subsistence income</u>

1. What is your annual coffee yield (in kg)?

2. What estimated percentage of your total annual income comes from coffee farming?

3. Which (non-coffee) tree products do you harvest? (Select all that apply)

- [ ] Fruits
- [ ] Firewood

- [ ] Timber

- [ ] Other (please specify): _____

3. What estimated percentage of your total annual income comes from (non-coffee) tree products?

4. What estimated percentage of (non-coffee) tree products do you use for subsistence?

## Appendix III: In depth semi-structured Interview

Agroforestry coffee farmers: Factors influencing tree incorporation

1. Where did you get your tree seedlings from?

2. Have you received agricultural extension services or training?

3. Have any institutional (NGO or governmental) programs incentivized you to plant trees?

If yes, please specify: _____

4. What were the main reasons for you to incorporate trees in your coffee farm?

5. What were the main factors influencing your choice of tree species in your coffee farm?

6. From your perspective, what are the main challenges faced by coffee farmers in implementing agroforestry practices?

Non-Agroforstry coffee farmers (if any): Factors influencing the decision to not incorporate trees

1. Have you received agricultural extension services or training?

2. What were the main reasons for you to not incorporate trees in your coffee farm?

3. Could you imagine incorporating trees in your coffee farm in the future?

If yes: What would incentivize you to take this step?

Perceptions of environmental and socio-economic impacts

1. How do you perceive the impact of your coffee farming system on the following environmental variables? (Scale of 1-5, with 1 being very negative, 5 being very positive)

- Pests and diseases

- Soil fertility

- Resilience to climate change

2. How do you perceive your coffee farming system in regard to the following socio-economic variables? (Scale of 1-5)

- Labour intensity (1 being very labour intensive, 5 being very labour extensive)

- Economic output (1 being very low, 5 being very high)

- Income stability (1 being very unstable, 5 being very stable)

3. Are there other environmental or socio-economic impacts/challenges connected to your coffee farming system that we have not talked about yet and that you would like to share?

## Appendix IV: Time plan

| Day | Thur. 29th | Fri. 1st | Sat. 2nd | Sun. 3rd | Mon. 4th | Tue. 5th | Wed 6th | Thur. 7th | Fri 8th | Sat 9th | Sun. 10th | Mon. 11th | Tue. 12th |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | | | | Kenyans day off - Wangari Maathai day | | | | | | | Kenyan's day off | | Go back to Nairobi |
| 8-9 | | Go to Gikirima | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | Breakfast + organising the day | |
| 9-10 | | | Prepare our general survey | | Take a drive around | Take a drive around | Do farm transect walk & mapping & soil samples - do one farm all together, split up after? | Do farm trasect walks / mapping & soil samples - divided groups | Semi-structured interviews at the farms & rankings - do one all together, afterwards split up | Semi-structured interviews at the farms & rankings- split up | | Semi-structured interviews at the farms & rankings- split up | |
| 10-11 | | | | | See different farms, do general survey around different farms | See different farms, do general survey around different farms | | | | | | | |
| 11-12 | | | | | | | | | | | | | |
| 12-13 | | | | | Lunch | Lunch | Lunch | Lunch | Lunch | Lunch | Lunch | Lunch | |
| 13-14 | Arrival at hotel | | | | | | | | | | | | |
| 14-15 | | | | | | | | | | | | | |
| 15-16 | | | | | | | | | | | | | |
| 16-17 | | | | | | | Talk about our findings & observations | Talk about our findings & observations | | | | | |
| 17-18 | | | | | Talk about our findings & observations | Talk about our findings & observations | Put our soil to dry | Put our soil to dry | Talk about our findings & observations | Talk about our findings & observations | | | |
| 18-19 | | | | | Work on tomorrow - make strata + radomized selection of farms | Work on tomorrow - make strata + radomized selection of farms | Generate semi-structured interview & rankings | Generate semi-structured interview & rankings | Improve semi-structured interviews & rankings or data analysis | Improve semi-structured interviews & rankings or data analysis | | | |
| 19-20 | | | | | | | | | | | | | |
| 20-21 | | | | | | | Start drawing our maps | Start drawing our maps | | | | | |

# Appendix IV: Additional Graphs

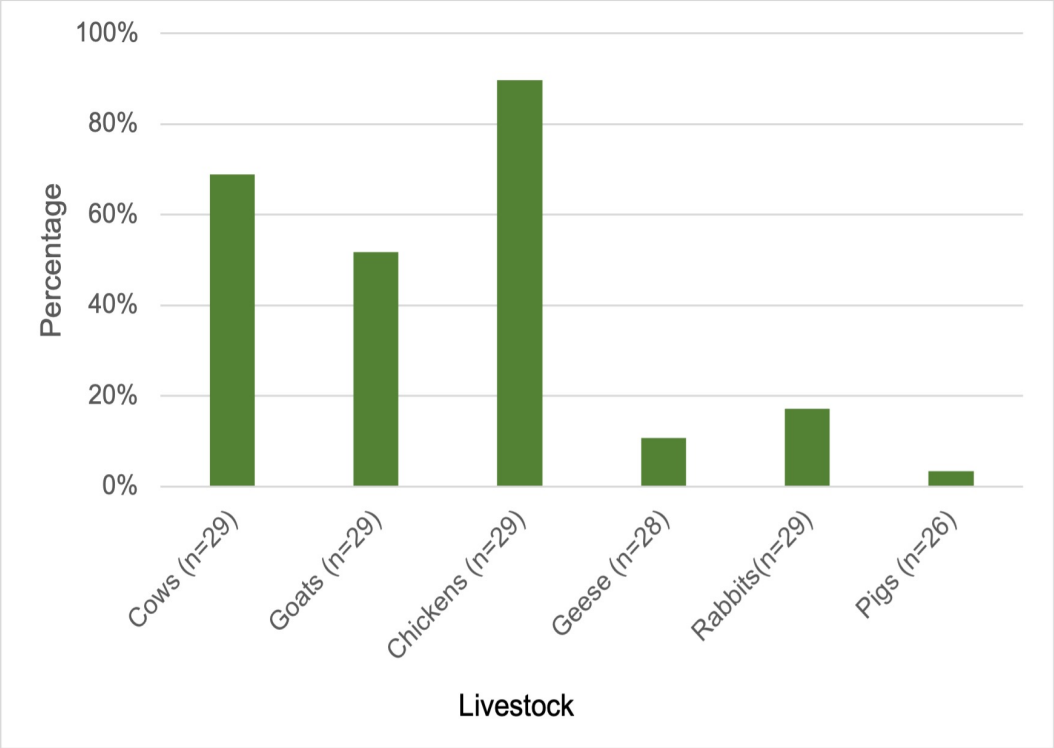


**Figure 14:** Distribution of livestock on farms

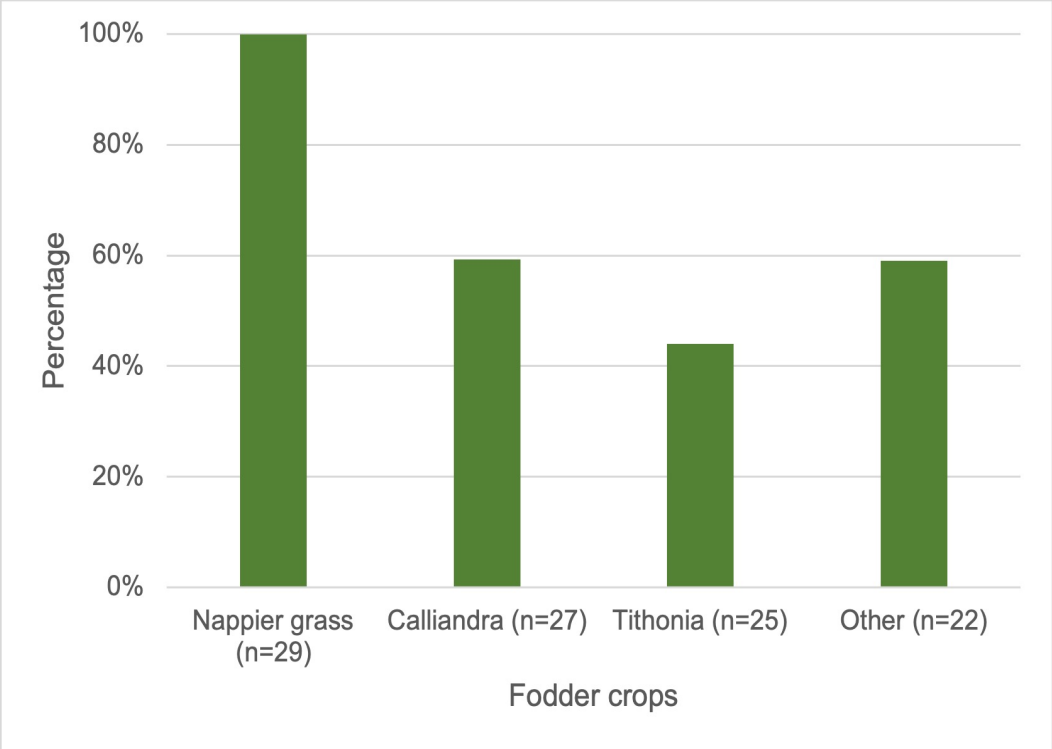


**Figure 15:** Distribution of fodder crops on farms