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Landscape restoration & sustainable livelihood through tree planting on agroforestry farms in Kenya

A farmer interview analysis

in the Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice

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Abstract

The global south is particularly affected by desertification due to the pressure on the resources of the increasing population and the climate variations. Agroforestry, the plantation of trees on farms, has been recognized for its great diversification potential to restore landscapes, preserve ecosystems and improve the livelihood of the local communities.

Although there have been a lot of emphasis on agroforestry projects in the last decades through many incentives or research projects, the establishment on larger scale is still hesitating.

The present report is the analysis of interviews that took place in 2017 and 2018 in the Kitui, Machakos and Makueni counties, located East of Nairobi in Kenya, under the leadership of the World Agroforestry Centre. Smallholder farmers received up to 42 tree seedlings to be planted on their farm and have been interviewed 6 to 8 months later.

The survival rate of the seedlings was of only 34,5% in 2017 and of 42,1% in 2018. Reasons for mortality are diverse such as pests, diseases, drought/rainfall or poor seedling quality. A special emphasis is given to the socio-economic conditions of the farmers, tree planting date and location, tree management techniques and the seven species of the project, from which only one is indigenous.

As trees on farm means additional labour and inputs, farmers need to get a return in form of tree products or services. Incentive measures are needed as trees are also a benefit for the whole society.

Keywords: On-farm trees – Exotic trees – Household surveys – Food security – Ecosystem services

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Dedication

I would like to dedicate this work to all the fellow students, I had the pleasure to meet on this journey of studying for a master degree,

in particular to:

Sumaia Binte Siddique, for her friendship and wisdom,

and Shruthi & Sudha Kottillil, for being both so welcoming and supportive,

I wish you all a bright future.

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List of Abbreviations

ACZ: Agro-climatic zones

a.s.l.: above sea level

EC: European Commission

FAO: Food and Agriculture Organization (from the United Nations)

FMNR: Farmer Managed Natural Regeneration

ICRAF: International Centre for Research in Agroforestry

IFAD: International Fund for Agricultural Development

IPM: Integrated Pest Management

KES: Kenyan shilling

NGO: non-governmental organisation

ODK: Open Data Kit

SALM: Sustainable Agriculture Land Management

SOM: Soil organic matter

SSA: Sub-Saharan Africa

UN: United Nations

UNCCD: United Nations Convention to Combat Desertification

CHAPTER 1 INTRODUCTION

Countering land degradation

Land degradation is one of the major concerns for human survival on Earth as it is reducing the agricultural land surface needed to produce food for everyone and destroying the ecosystem functions primordial for human health and well-being.

The world population is planned to increase from actually 7,8 billion to 9,7 billion inhabitants in 2050[1] and already 40% of the world surface is used for agricultural purposes making it the biggest ecosystem of the planet (EAT-Lancet Commission, 2019). Additionally, if there is no fundamental changes, human diets are evolving towards higher content in meat and dairy products, that also lead to an increasing demand in available agricultural land.

Sub-Saharan Africa (SSA) is particularly affected by land degradation as 65% of the soil in the region is already deteriorated and subject to desertification, the main reasons are lack of fertilizers, soil erosion and soil acidification (Zingore et al, 2015). Crop cultivation is impaired as well as animal husbandry. Smallholder farmers are the ones dedicated to extract the last nutrients of those soils; poverty and low productivity forcing them to employ unsustainable agricultural practices putting even more pressure on available resources. The term 'smallholders' refers to the limited resources of the farmers and depends on the activities and economical returns in the region, nevertheless in sub-Saharan Africa, the majority of the rural population is considered smallholder farmers (FAO, 2004). Most of them cultivate for their own consumption and sell surplus if any.

There seems to be no relaxation soon. In 2016, one person of fourth in SSA was still suffering of chronic hunger (FAO, 2017b) and the population in the continent is expected to almost double up to 2050 from approximately 1,3

1 https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

billion inhabitants in 2020 to 2,5 billion in 2050[2].

Additionally, the climate variations are leading to irregular rainfall patterns, are increasing the soil erosion and are extending the periods of droughts, which are often preceded or followed by floods.

Droughts are affecting up to 70 countries worldwide as per the information communicated early this year by Ibrahim Thiaw, executive secretary of the United Nations Convention to Combat Desertification (UNCCD) and half of the global land is subject to be drylands in 2050 leaving big parts of the population food insecure. In Kenya, for instance, the periodic droughts and floods are affecting smallholder farmers economically, socially and environmentally as they rely on regular rainfall patterns for their activities (Ochieng et al, 2016). Additionally, temperatures in Africa are expected to increase by 3 to 4 degrees by the end of this century according different climate models (Brian et al, 2013).

There is an urgency to maintain and enhance cultivable land in SSA. The aim is not only to ensure food security, but also to bring a perspective to the agricultural sector and restore the landscape and ecosystems, and preserve natural resources and biodiversity. Land restoration ensures also a positive trend against deforestation as more agricultural land is made available and less forest need to be destructed.

However, there is no easy solution: the overuse of synthetic fertilizers (Addiscot, 2004) and chemicals as it is the practice in most industrialized countries or the intensive irrigation as it has been promoted in India (Dhawan, 2017) lead to a short term success but are not in balance with the environment and cannot be considered as sustainable practices (Porter & Francis, 2017). The risks are water contamination (Addiscot, 2004; Wick et al, 2012), water depletion (Dalin, 2017), soil salinization (Singh, 2015), monoculture and low biological diversity (Altieri, 2009). To reach sufficient yields and economic viability while preserving landscape and ecosystems is

2 https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

definitively a challenge.

A very important aspect concerning the political position of SSA countries, is that each country can become independent from food imports.

Since decades trees on farms -agroforestry- is widely promoted in many regions of the world especially in semi-arid zones[3]. Agroforestry is not only helping to protect the environment and restore land but is also accompanied with socio-economic benefits (Swaminathan, 2017). Diversified farming concept with mixed crops, trees and livestock is a response to the distress of rural Kenya (Nyberg et al, 2020).

Agroforestry and its benefits

Agroforestry is the combination of trees or shrubs with crop cultivation or pastureland on the same plot. This land use system is not new as trees have been part of the agricultural landscape in many countries since centuries (Nair et al, 2008).

The land use can be *sequential* if the trees are alternating with the crop or if their maximum growth periods are rotating. It can be *simultaneous* where trees and crops/pastures are cultivated together (Buresh & Tian, 1998). Aim is to reach optimum crop and land productivity.

Agroforestry can take very different forms, for instance: *alley cropping* where the trees are planted in rows between crops, trees are then preferably fast-growing and leguminous trees, and need to be regularly pruned to keep low shade levels for crops; it can be also simply in *home-gardens*, with many trees of different heights, this is called 'multilayer'; in the case of *improved fallow*, trees are also preferably fast-growing and leguminous and are planted, in the years where there is no crop, to improve soil fertility and generate extra revenues; *shaded perennial-crop systems* are also a well-known option where shade-tolerant crops such as coffee or cacao are grown under the canopy of

3 Hot semi-arid climate is classified as BSh in the Köppen-Geiger climate classification

commercial trees (Nair et al, 2008).

The question is not if agroforestry is a recommended practice but about how to implement it and which benefits are expected of each specific agroforestry system.

Agroforestry has been more intensively promoted in the 1980s and 1990s to counter the increasing problems such a tropical deforestation, fuel wood shortages, soil erosion and biodiversity loss (Nair et al, 2008).

Although it is a common understanding that farm concepts based on agroforestry are beneficial, the adoption is slow, and reasons may differ from place to place. One reason mentioned in the study of Jerneck & Olsson (2013) is the lack of social studies: farmers need food security and entrepreneurial skills to engage in agroforestry, especially because the readiness to take risks is necessary, and that is, according to the study, mainly taken by men.

Also, the study of Hughes et al. (2020) demonstrated that practices of agroforestry in West Kenya did not lead to much increase in household incomes or possessions while compared with a control group.

Indeed, agroforestry may bring different benefits:

- offer an economic stability to the farmer and increase his resilience through the products and services of the trees such as timber -the most important use according to the study of Reppin et al (2020) -, fuel wood, fruits, medicinal products, fodder, gum and the diversification on farms offered;
- restore degraded land subject to desertification or which has been affected by deforestation and permit the cultivation where no success could have been expected otherwise or simple increase the yields of the neighbouring crops;
- preserve ecosystems, landscape & biodiversity;
- be a tool for carbon sequestration (Hughes et al, 2020).

So, depending on the benefit sought and depending on the local conditions, that can vary over time such as climate, household structures or policies in vigour, the agroforestry practices need to be different and the recommendations as well.

There are diverse processes where agroforestry is reversing land degradation:

- soil fertility improvement: it can be achieved through atmospheric nitrogen fixing trees due to *Rhizobia* or *Frankia* bacteria which interact with the roots of the tree (Rosenstock et al, 2019), most leguminous trees have this ability; deep-rooted trees also retrieve nutrients that are out of reach of the annual crops and can be given back to the top soil through biomass deposition (branches, leaves, roots); additionally nutrients are made available through mineralization of soil organic matter (SOM) (Buresh & Tian, 1998);
- soil physical properties get improved with trees as well as the microbiological activities (Nair et al, 2008). Indeed, trees are creating a suitable biologically active area, for instance while restoring a soil fauna or enabling a macro-fauna such as earthworms, micro-arthropods, termites and ants (Buresh & Tian, 1998);
- minimization of soil erosion due to rain or wind, especially on slopes; soil & water conservation leading to better water infiltration (Nair et al, 2008). Leaching processes are strongly reduced as water remains stored in the soil with tree roots and acts as a barrier (Buresh & Tian, 1998);
- biodiversity through better landscape connectivity. In the tropics 90% of the biodiversity is located in populated areas (Nair et al, 2008);
- shade and micro-climate.

However, the effects can be also negative as trees and crops may compete for nutrients, water, and light (Nyberg et al, 2020). Also, there are allelopathic effects, where chemicals from the trees are harmful to the neighbouring crop (Kurauka, 2015) or trees may attract pest or be a disease vector (Nair et al, 2008).

Concerning the carbon sequestration, the paper of Hughes et al (2020) mentions how Vi Agroforestry a Swedish NGO created in 1983 promoted tree plantations in the West of Kenya. As one of the projects was explicitly carbon sequestration, farmers got not only free seedlings but also the equivalent of 3$ per year to plant and maintain the trees, this is the so called 'carbon payment'.

Jerneck & Olsson (2013) mention that the study of agroforestry moved from a historically descriptive perspective with the analysis of the different species available in farms to an economic approach, where a clear benefit is expected directly from the tree or through its biological services. Nevertheless, studies linking tree species with socio-economic and environmental benefits are still lacking (Kurauka, 2015).

As there are many levels of analysis and many factors that interact with each other including e.g. the search for the right species for a specific farm or village, the study of agroforestry is not an easy task. Therefore, in order to gain knowledge at a local level, the present report is dedicated to a project that took place in 2016-2018 in East Kenya under the leadership of World Agroforestry Centre (ICRAF).

Aim & objectives of the study

This research is aiming at being a contribution to land restoration and poverty alleviation in sub-Saharan Africa. More specifically the research focuses on the performance of trees on farms as it is recognized as having high potential in restoring ecosystem services, benefiting the landscape and improving livelihood. Consequently monitoring and evaluation of agroforestry projects is a mandatory approach to develop and improve scientific & practical knowledge at a local level.

The World Agroforestry Centre project consisted of a 'trees on farm' development program, where smallholder farmers could receive up to 42 tree seedlings for their own planting and management. It was located in three counties of East Kenya: Kitui, Machakos and Makueni and follow-up reviews took places in 2017 and 2018, six to eight months after the tree planting. World Agroforestry (ICRAF) was the leading organization in collecting the tree and household data, the project being part of the "Restoration of degraded land for food security and poverty reduction in East Africa and the Sahel: taking successes in land restoration to scale" initiative, IFAD-EC funded. The surveys have been conducted in order to identify the context-specific variables that affected the success of the restoration measure (Magaju et al, 2019a/b). Therefore interviews were not only focusing on facts about the trees but also included socio-economic data of the farmer households.

One of the main results is the survival rate of the tree seedlings, which was of 34,5% in 2017 and of 42,1% in 2018. The purpose of this report is to understand the context leading to those values.

More precisely the main objectives that will be answered through this dissertation are:

- establish from the socio-economic data an understanding on farmer households' conditions and the characteristics needed for successful implementation of trees on farm,
- find out the key factors for the survival of planted trees from the data contained in the two surveys, mainly considering timing, climate, tree species, location and tree management practices,
- get an overview of the seven species of planted trees in the project and find out how they contribute to improve livelihood and maintain ecosystem services also considering gender aspects and farmer preferences and experiences.

The three following objectives are the leading frame of each following chapter.

This work is to be addressed to World Agroforestry Centre (ICRAF), the local governmental or non-governmental organisations (NGOs), especially those organisations located in the three counties of the studies. The experience that took place in those years needs to be acknowledged and communicated in order to plan future steps on a continuous improvement basis. Some data have been already reworked in presentation or report from World Agroforestry Centre (Bourne et al, 2019; Crossland & Paez-Valencia, 2020); this report is a complement. This work can also be used by research teams from similar semi-arid regions for comparison with their own data. With this work, agroforestry farms are to be better understood for a more successful implementation.

CHAPTER 2 MATERIAL AND METHODS

Study area

The farmer interviews took place in the Kitui, Machakos and Makueni counties in Kenya (Figure 1) and more specifically in seven sub-counties (Figure 2) within those three counties, which are Kitui rural and Mwingi central (Kitui), Masinga, Yatta and Mwala (Machakos) and Mbooni and Kibwezi East (Makueni).

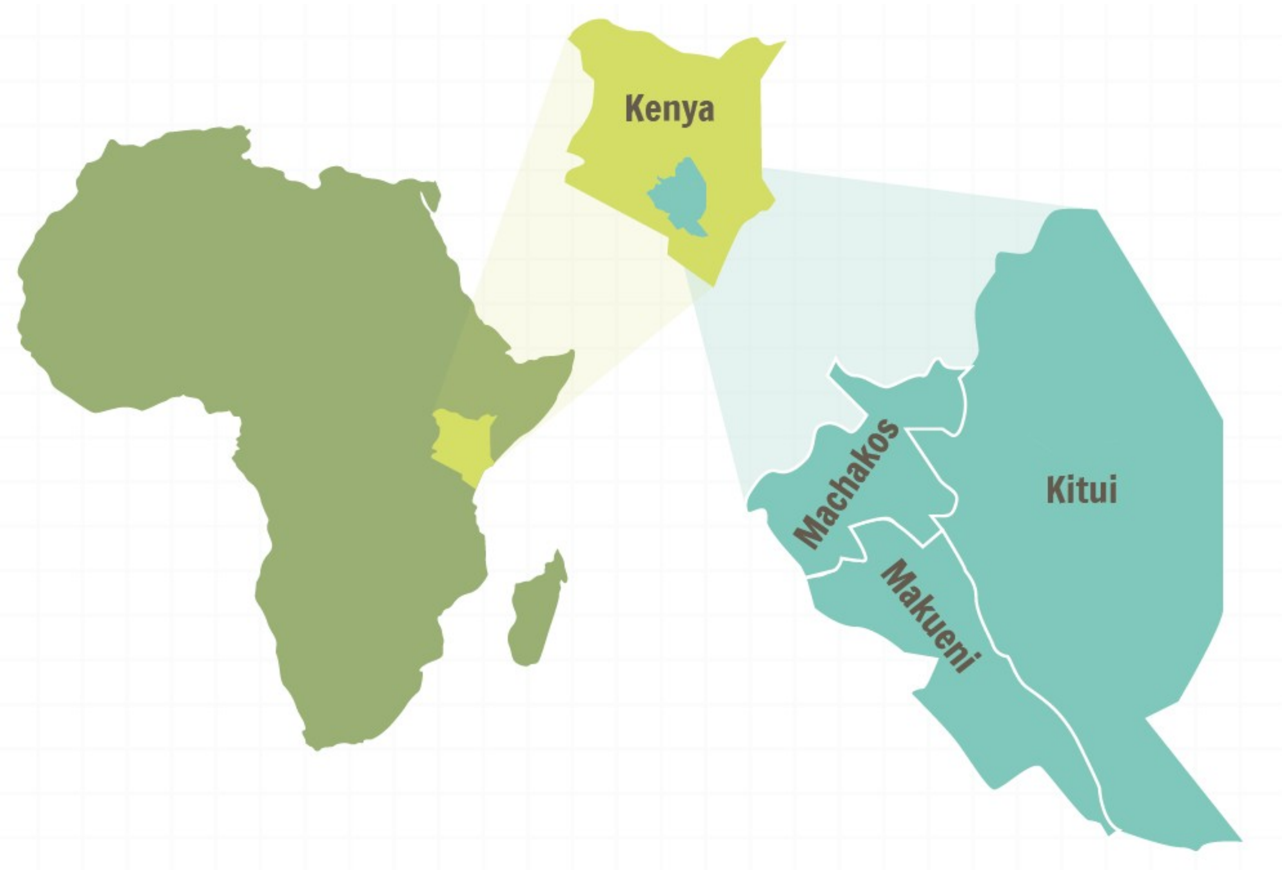


Figure 1: Kitui, Machakos and Makueni counties in Kenya

Source: Crossroad & Paez-Valencia, 2020

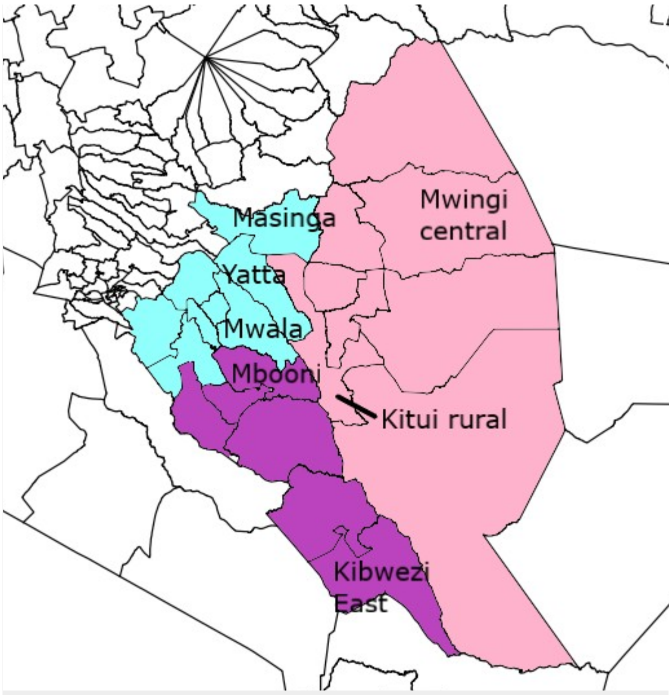


Figure 2: Sub counties in Kenya where the interviews took place

Source: Shape file retrieved from https://data.humdata.org/dataset/ken-administrative-boundaries

The climate data in Makindu (Makueni) and Mutomo (Kitui) has been retrieved from www.en.climate-data.org and saved in the appendix 1 where temperatures (minimum, average and maximum) for each month as well the average precipitations are displayed. Both cities are in the hot semi-arid climate (BSh) according to the Köppen-Geiger climate classification. Kenya has many climate types as per Figure 3 within the tropical (A), dry (B) and temperate (C) range.

The temperatures in Makindu and Mutomo vary during the year between 15°C and 30°C with an average of about 23°C. Precipitations are for both cities in the range of 600-700 mm per year, where the months with higher rainfall amounts are November, December and April.

As a complement, the map from GoogleMap of Kenya is reported (Figure 4).

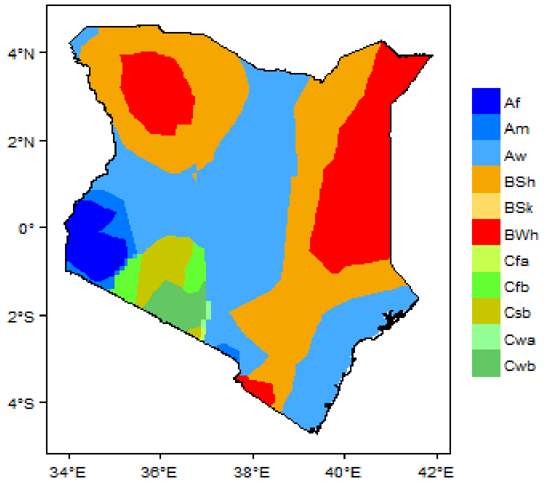


Figure 3: Map of Kenya with Köppen-Geiger climate classification

Source: http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Kenya

Immagini ©2020 TerraMetrics,Dati cartografici ©2020 100 mi

Figure 4: Google Map, Kenya, retrieved on 4/4/2020

The satellite picture shows a lack of vegetation cover except in the South-West and along the coast. The area around Kitui, where the study takes place, has some vegetation. Land cover in this area is mainly "Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)", type 14 according to Africa Groundwater Atlas (2019). The terrestrial surface of Kenya is 580.367 km^2 and the population in 2020 is estimated to 53,8 billions inhabitants[4] according to the UN projections. The county area of Kitui is 30.430 km^2, Machakos 6.043 km^2 and Makueni 8.009 km^2. According to the 2019 census results (Kenya National Bureau of Statistics, 2019), Kitui has 1,14 million inhabitants, Machakos, 1,46 million and Makueni, nearly 1 million.

The device used by the enumerators were gathering automatically latitudes and longitudes of the plots, and the gathered data were in following range:

Kitui: latitudes from 0° 44′ to 1° 46′ South (of the Equator), longitudes from

4 https://population.un.org/wpp/Download/Standard/Population/

37° to 38° 14′ East; Machakos: latitudes from 0° 49′ to 1° 34′ South, longitudes from 36° 47′ to 38° 8′ East; Makueni: latitudes from 1° 6′ to 2° 44′ South, longitudes from 37° to 38° 14′ East.

The median values of the altitudes of the farms in Kitui and Makueni varied between 800 and 1000 m a.s.l. and was about 1200 m a.s.l. in Machakos.

Material

The main material consists of the farmer interviews that took place in June 2017 and July/August 2018 in Kenya. The files are publicly available under https://data.mel.cgiar.org/dataverse/SRPFIVE and are named 'Tree planting data 2017 – Kenya' and 'Tree planting data 2018 – Kenya' respectively. They are both in the reference list of this document under Magaju et al (2019a) and Magaju et al (2019b). For reason of simplicity, this report will not cite the source each time the two databases are used as they are building the core of this dissertation. The documents have been produced by World Agroforestry Centre (ICRAF).

Each database is made of four 'comma separated values' files (csv files):

- 'DataDictionary_Introduction' consists of a short text for description, methodology, summary, as well as the survey start and end dates, author and co-authors. The methodology mentions the use of the open source software Open Data Kit (ODK) where questions and answers of the interviews are saved. This software can be used with the corresponding ODK app after a training, which has been conducted with the enumerators and the community facilitators conducting the interviews.
- 'DataDictionary_ElementDescription' gives the description of all variables of the survey for a tree. In 2017, there were 29 variables per tree, in 2018 it increased to 311 variables per tree as the survey was completed with socio-economic data. The interviews were structured as the

completion of all required variables was needed and there were only few free text entries where farmers could express themselves freely. The list of all those variables can be found in appendix 2.

- 'DataDictionary_UniqueIdentifiers' refers to a FAO link to identify the different planted tree species.
- 'Tree_Planting_Data_2017' and 'Tree_Planting_Data_2018' respectively are the most important files, as this where the data from the interviews are saved in a tabular form.

The 2017 interviews contained 14.804 entries, which means that 14.804 single trees have been surveyed. The 2018 interviews contained 17.520 tree entries. The evaluation of the survival has been made on 17.517 trees as three trees had no survival response because they were not planted. There were, in fact, more trees not planted but farmers could give an answer about tree survival.

The number of households (counting the number of different household IDs in each database) is of 1286 in the 2017 survey and 1416 in the 2018 survey.

As the surveys were performed on two consecutive years, this is a good basis for comparison.

Methodology

The csv files of 'Tree_Planting_Data_2017' and 'Tree_Planting_Data_2018' have been uploaded in the two open source software 'R Studio' and 'LibreOffice Calc'. In R studio, many data could be dispayed through simple functions such as 'summary' or 'table'.

The methodology is inductive, it means conclusions are drawn from the existing observations or while doing cross analysis between the different variables. A deductive methodology was not possible as this work is based on already existing interviews.

After extracting the data, the majority of the variables have been presented in the 'results and analysis' chapter. It allows the readers to have their own insights, on what they would have liked to deepen. Also, the results have not been presented in the same order as the questions of the interviews but have been sorted to present a gradual understanding of the data and be grouped as per the objectives of the study.

The analysis was not based on the three counties but on the seven sub-counties to obtain a more detailed analysis, which was more appropriate for comparison. Conversely, the information available at finer scales, which were the 'ward', the 'location', the 'sub-location' or the 'village' of the survey, were not taken into account to avoid an overdispersion of data.

The decision, where to deepen the analysis, came with time after having reviewed all entries one by one.

The three objectives of the study are the leading phrase throughout the report and the methodology is also split into those three parts.

Socio-economic analysis of the farmer interviews

From the original main data frame containing all tree entries, a smaller data frame has been created where every household ID appears only once. The command used in R Studio is: `tabhousehold <-tab[!duplicated(tab[,1]),]`, tab being the data frame with all tree entries and the first variable being the household ID. This approach allowed to overcome the problem possibly arisen by an uneven distribution of the number of trees per family. Households with more trees - the maximum amount of trees per family was 42 - would have had a stronger weighting leading to a bias in the results. This created data frame has 1416 household entries (from 17520 tree entries).

'Age, gender & responsibilities within the farm'

This section starts with the utilization of variables 6 to 12 of the interview, which describe the household (the list of those variables is in appendix 2). Those variables are first the age of the household head and its gender. The age distribution of farmers is represented with the help of the function 'summary' and through a histogram with R Studio. The tree survival rate (variable 300) has been displayed in function of age and gender of the household head. Here, the complete data frame with all tree entries have been used and not the household data frame because the survival rate is related to trees and not the household. In case of the household head age, the value of the survival rate is more robust if many trees have an owner with that age. Although the data has been retrieved from R Studio, the XY plot, is from LibreOffice Calc. Two regression lines has been also displayed (linear and polynomial) to have a trend.

Then, the relationship of the interviewed farmer with the household head (there were nine possibilities to choose from) has been displayed. The gender of the interviewed farmer could be deducted from her/his relationship with the household head in case she/he was the spouse.

Finally, the number of adult men and adult women in the household, and from the adult men and women in the household, how many of them are working in the farm has been represented through histograms in R Studio.

The variables 79 to 173 were about responsibilities on the farm, namely digging, manure application, mulch application, fertilizer application, watering, fencing and pruning, and the identity of the person, who performed the activity. The choice was between the farmer, the farmer's wife/ husband/ daughter/ son/ grandmother/ grandfather/ father/ mother, the household head or other people. There is a redundancy as household head is also the interviewed farmer or one relative. For digging, additional questions were about hired personal. Also the time requested to perform each task was recorded as well as the frequency of pruning. This information has been summarized in the 'Results and Analysis' chapter.

Finally, variables 174 to 199 depicts how tree planting and tree management affect the time spent working on the farm. Here only the percentage of households, where time on farm increased, decreased or kept the same has been mentioned, the affected activities have not been pursued further in this report to keep a focus.

'Food security and migration'

The second section starts with the variables 38 to 64, where farmers were asked how they cope with food shortage with different options to choose from, the difficulties faced in the last 12 months such as worries, lack of nutritious food, skip meals... Also the migrative background of the farmers and their parents have been asked as well as about household members that migrated or are planing to migrate. Again the information is summarized in a text.

'Access to land and investment priorities'

Finally a third section has been generated from variables 13 to 37 and 65 to 78. First the questions went towards the land, the household had access to in the previous 12 months. The histogram depicting the land surface distribution has been generated with R Studio. Before data were harmonized into hectares as values could be also given in square meters or acres. Then, for different ranges of land surface, the tree survival rates have been extracted through R Studio asking the number of trees that survived and that did not survive for each range, this can be easily done with the function 'table'. Then, the land surfaces by tenure type (rented/ borrowed/owned/others) were requested in the interviews and if they were secure; here the information has only been summarized, as the bigger part of the land was owned, there were not much reasons to go in more detail. Also, plot distances from the home has been displayed. Concerning the investment priorities the farmers had 9 choices how they would invest 25.000 KES (Kenyan shilling). Then the last three variables of this section are open text: first the reason of investments, then additional land restoration/ land management options and finally additional comments. At this stage the farmers gave many answers and this have been viewed through the filter function in LibreOffice Calc and summarized in bullet points.

Factors of tree seedling survival

In this sub-chapter the data base of 'Tree planting data – 2017' as well as 'Tree planting data – 2018' has been used.

'Planting date & climate'

The planting date is only one entry (variable 12 in 2017/ variable 277 in 2018), which has the form YYYYMMDD, this is not a continuous variable. The first task has been to get a rough distribution of the planting dates in order to know the main planting periods. After it has been identified that the main planting period in both years was from October to December. In order to be able able to display the histograms easily the date has been transformed in calender weeks, then the distribution per week of the trees that survived has been displayed and the same histogram has been generated for the trees, which did not survive. The reason was to investigate if the planting week can affect the tree seedling survival. With a representation of the survival rate only, the quantities of trees in each period would be missing.

Then, the climate data from worldclim.org has been prepared in QGIS 3.10.5 matching the data with the shape file showing the sub-counties. It has been generated from the two main observation periods from October 2016 to June 2017 and from October 2017 to June 2018 on a monthly scale. In order to know how is the climate during the rainy seasons in other years, the data from October to December has been generated as well for 2013, 2014, 2015 and 2018. The scale for the precipitation has been chosen with a maximum value of 400 mm to be able to see the changes in the dryer months although in November 2017 rainfall went to values above 600 mm.

Finally, tree heights and diameters have been displayed with R Studio using the function 'boxplot' and 'plot'. Tree heights and diameters are under variables 21 and 22 in 2017 and variables 301 and 302 in 2018. These plots have been displayed in the appendix 3 differentiated by species. The boxplots have been displayed without outliers as some of those outliers were probably a mistaken entry or were distorting the representation. Indeed, the purpose is to observe the main tree growth tendencies and not the specificities/ abnormalities of single trees. For the XY plot of the tree diameters in function of the heights, some self-defined outliers have been taken out manually in order to allow a better display. These were the trees with higher values of height or diameter, the limit was different for each tree species and no more than 5 outliers have been taken out per tree species, the outliers listed is mentioned along with the plots in the appendix 3.

'Tree species and location'

Then, the survival rate of the seven trees species has been displayed using the survival rate (variable 20 in 2017 and variable 300 in 2018) and the species (variable 11 in 2017 and variable 273 in 2018). The data has been extracted from R Studio with the function 'table' meanwhile the table and bar diagrams have been generated by LibreOffice Calc, the latter only because of easiness of use. Then, the same procedure has been repeated for the survival rate at the different sub-counties with this time variable 5 (2017) and variable 268 (2018) for the sub-counties. Then, the question arose, if the survival rate in a sub-county could be deduced from the survival rates of its tree species: a bar diagram of species distribution per sub-counties has been generated for both years. This has not been further developed because the tree species survival rates differed too much between the two years.

Then, the altitude, only available in 2018 with the variable 264, was displayed by a boxplot per sub-counties. As there was a clear split with the Machakos counties above 1100m and Kitui and Makueni below, so that an additional bar diagram has been prepared with survival rate of species depending on those two altitude ranges. Data were cross checked with survival rates of sub-counties/ counties on both years.

The niches, under variable 13 in 2017 and variable 275 in 2018, were a multiple choice between eight options. In the same way as above with the survival binary variable and the 'table' function number of trees that survived and that did not survive have been extracted, summarized in a table and represented with a bar diagram from LibreOffice Calc. One further combination seemed interesting, namely to know if farmers had preferences in planting a species in a specific niche and how trees survived. The correspondence analysis has been used as it allows a graphical representation on two axis where relation between niches and tree species is shown. Correspondence analysis is an extension of principal component analysis for categorical data and it is often used in the context where species are located in their natural habitat. The commands for correspondence analysis are from the class of Dr Neeti provided in 2019 at TERI school of advanced studies in New Delhi. Correspondence analysis has been applied and displayed for the 2017 and 2018 data and for all trees and then, only for the tree that survived.

'Tree management practices'

The planting hole size under variable 15 (2017) and 278 (2018) is a multiple choice variable with three options and has been again presented in a diagram bar. The following variable, the planting hole size in case the first answer was 'Other', has been represented in the same way as the planting date with histogram comparing the distribution when the tree survived and when it did not, for both years. Again displaying the survival rate for the different hole size range, would not have allowed to see but the information on the quantity of trees in this range. Survival rate values have been given in the text.

The manure and mulch application, variable 17 & 18 in 2017 and 280 & 284 in 2018, has been displayed in two graphs, one for each year, with the quantities of trees without any addition, with manure only, with mulch only and with manure and mulch, one bar shows the trees, that survived and a second bar, how many trees did not survive. Again the data has been generated in R Studio and displayed in LibreOffice Calc. It was crucial here to consider the case where manure and mulch where applied on the same tree. In 2018 the frequency and quantity of manure application (variable 281 and 282) has been also gathered and represented here in a table and histogram. The measurement method (variable 283) is a multiple choice simply displayed as a percentage in the text. The same procedure has been done on variables 285-287 for mulch. Manure & mulch application quantities and frequencies have not been further investigated in this report as it may not lead to more knowledge because the majority of the farmers applied 1 or 2 kg of manure or mulch, and application since the planting was one or two times.

Then variable 19 (2017) is binary and asked if watering was applied and variables 288-299 (2018) asked informations on synthetic synthetic fertilizer, watering, pruning, fencing and shade. Results have be written in form of text or percentages. The frequency of watering has been completed with the corresponding survival rate. Also, for watering, fencing and shade, a table has been created to display the increase in survival rate of each species in case watering, fencing or shade was applied.

'Reasons of non-survival'

The reason of survival for the year 2017 (variable 29) were induced from the last variable called 'notes'. It has been reworked using LibreOffice Calc and its filter option, and sorting the responses in categories. Where more than one reason has been mentioned only the first one has been chosen as it is expected that it is what was the more important to the farmer.

In 2018, the farmer could say 'yes' or 'no' to 7 reasons (variables 303-309), so that a more exact distribution could be proposed in form of percentages. An additional field (variable 310) was for 'other' where an open text has been entered and here the data has been summarized in categories and quantified (number of times that a reason have mentioned).

Tree species and ecosystem services

This section is aiming at widening the perspective and considering the trees with all their functions. The definition of ecosystems and ecosystem services will be reminded and through a brainstorming, examples of the four categories of the ecosystem services of trees on farm are given.

Then the tree species have been described in one page mainly based on the “agroforestree” database from ICRAF, this part is located in the appendix 5, some photos have been added for each tree species to enhance the understanding of each tree species. The aim is to gain knowledge about the different tree species and relate or explain some results from the interviews with the information available in the literature about the tree species.

A short description of each tree and a tree species information matrix brings the information available in agroforestree in a compact form.

Then, the following paragraph is dedicating to the farmer's choice for a particular tree species. The choice of tree species has been represented by household head gender though two pie charts made again in LibreOffice Calc (the already mentioned variable 7 and 273 have been used). Then, the list of species, which have planted outside the project, has been displayed in order to put into evidence the farmer preferences. The same exercise has been done for potential future tree plantings. Two histograms show the quantities of trees that have been planted or that is planned to be planted per household. Then, the farmers have been requested to answer questions about tree management techniques she/he will use for those additional trees and the farmers, that will not plant additional trees, gave some reasons about it. The information were in variables 236-257, this is displayed in the form of a text.

Finally with variables 258-261, the tree survival rate of the second-year farmers could have been compared with those of the first-year farmers and the products and product uses mentioned by the second-year farmers have been listed. Also, the tree species chosen by first and second-year farmers have been displayed with pie charts from R Studio to recognize if the farmer preferences are changing after having being part of the project during one year.

CHAPTER 3 RESULTS & ANALYSIS

In this chapter, the results and analysis are proposed in an interwoven form.

The first sub-chapter is based on the household survey of 'Tree Planting Data 2018' containing the socio-economic data of the farmers. The focus is on the household head age and gender, farm responsibilities between family members, food security, migration history and future plans, access and security of land tenure as well as aspiration of future investments.

Then the second sub-chapter is looking toward the factors that affected the survival rate of tree seedlings, principally related to planting date & climate, location of the trees and different tree management techniques, finalizing with the reasons for the non-survival of the trees as given by the farmers.

A third sub-chapter will focus on ecosystem services and the different tree species as well as the farmers species preferences with a focus on gender and experience.

Socio-economic analysis of the farmer interviews

The focus of this sub-chapter is on the households. All data are from the second survey, that took place in 2018.

First, the demographic data such as age and gender are examined for the household head. The different tasks to be performed on the farm are reviewed, especially the activities related to tree planting and management.

Then, some more information such as food security and how farmers cope with food shortage as well as their migration background are getting analysed.

Finally, the land at disposition of each household and the investment priorities are observed, with a complement on land restoration measures.

Age, gender & responsibilities within the farm

This paragraph is helping in providing more knowledge on the farmer's identity and the relationships within the households. Some questions were directly related to the household head meanwhile other questions were about the interviewed farmer, who was either the household head or another person.

The average age of the household head was 50 years, minimum age 23 years, 1^{st} quartile 42 years, median 49 years, 3^{rd} quartile 58 years, maximum age 97 years.

In following histogram (Figure 5), the numbers of farmers within an age interval are displayed. The majority of the household heads were between 41 and 45 years old.

Figure 6 shows the survival rate of trees sorted by the age of the household head. The graph is accompanied with two regression lines, which helps recognizing the age groups with lower survival rates, which are the older farmers and to a lesser extend the youngest farmers.

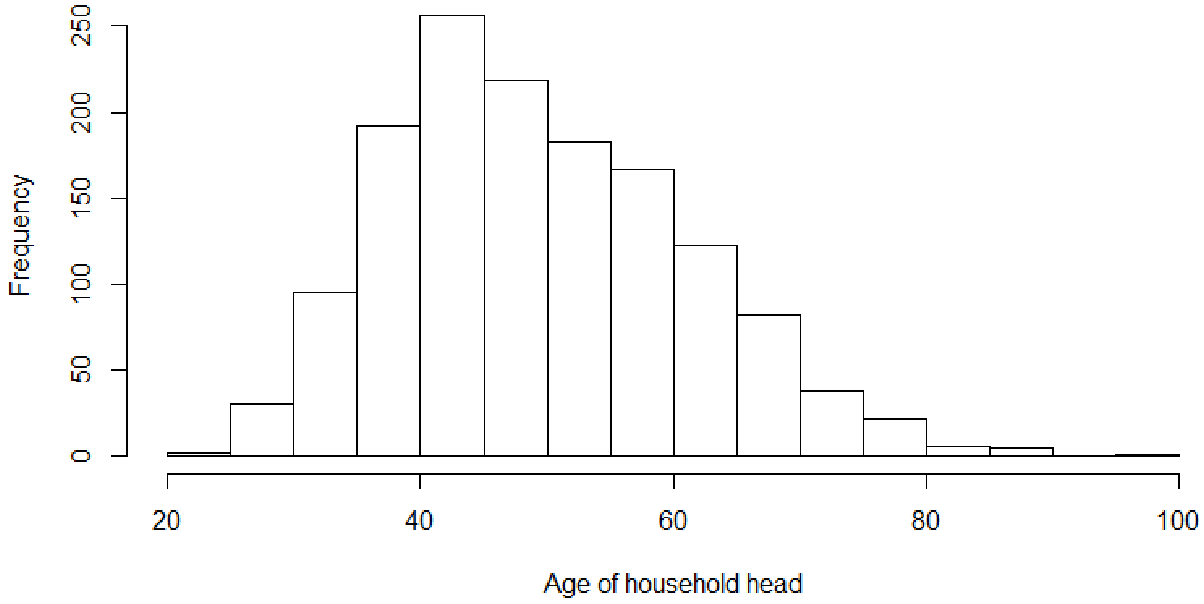


Figure 5: Histogram age distribution of household head

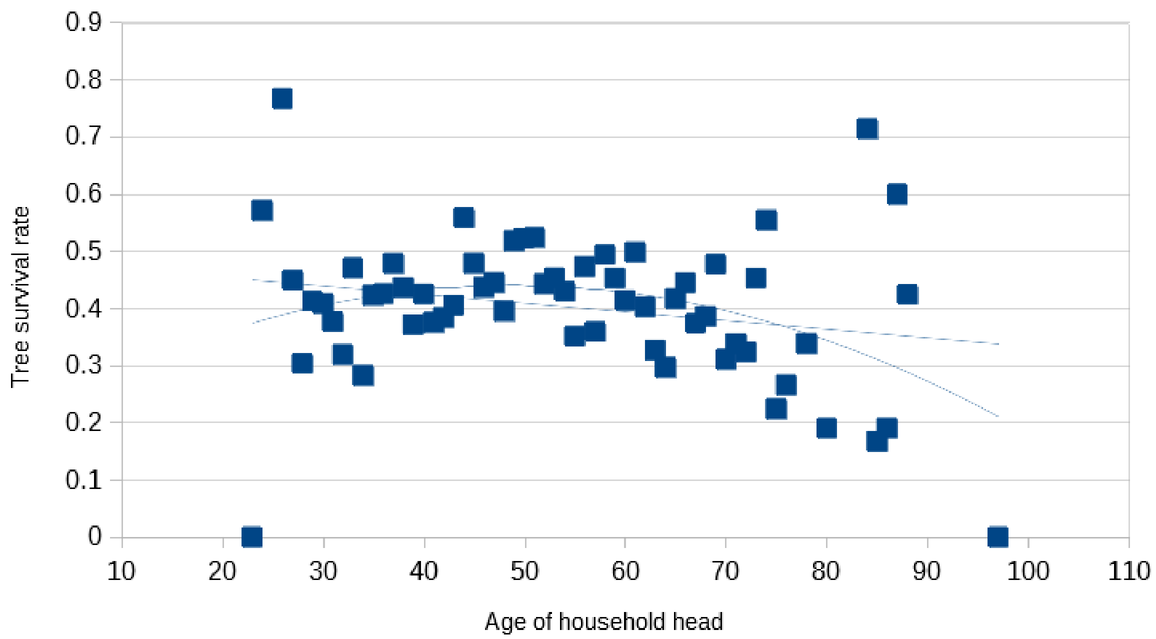


Figure 6: Tree survival rate in function of the age of the household head with linear and second degree polynomial regression curves

Among the household heads, 1008 were men (71,2%) and 408 women (28,8%).

Trees having a woman household head had an average survival rate of 43,6% against 41,6% for trees from a male household head.

In 544 cases, the household head answered the survey, in 812 cases it was one of the spouses of the household head, in 47 cases it was the son or daughter of the household head, in 12 cases it was another relative or person, in 1 case it was the grandchild.

The age and gender of the interviewee was not recorded but the gender can be deducted from the household head gender if she or he is the spouse of the household head. It has to be the opposite sex as homosexuality is banned in Kenya (Khan, 2019).

In the 1008 households where the head was a man, 308 times the interview has been answered by the male household head himself, 663 times by a spouse and 37 times by another relative. In the 408 households where the head was a woman, 236 times the interview has been answered by the woman household head herself, 149 times by her husband and 23 times by another relatives. To resume, there were 308 + 149 = 457 times a man answering the interview and 663 + 236 = 899 times a woman, the other relatives appeared 60 times but their gender were unknown. So, males (32,3%), females (63,5%) and unknown (4,2%) answered the interview.

(There are still some enigmas as in 32 households whose household head was a man, there is no adult man in the household. And in 8 households whose household head was a woman, there is no adult woman in the household. So, it seems the household head was not always counted as part of the household).

The histograms (Figure 7) shows how many adult men and women were in the households and then how many adult men and women from the household worked on the farm in the previous 12 months.

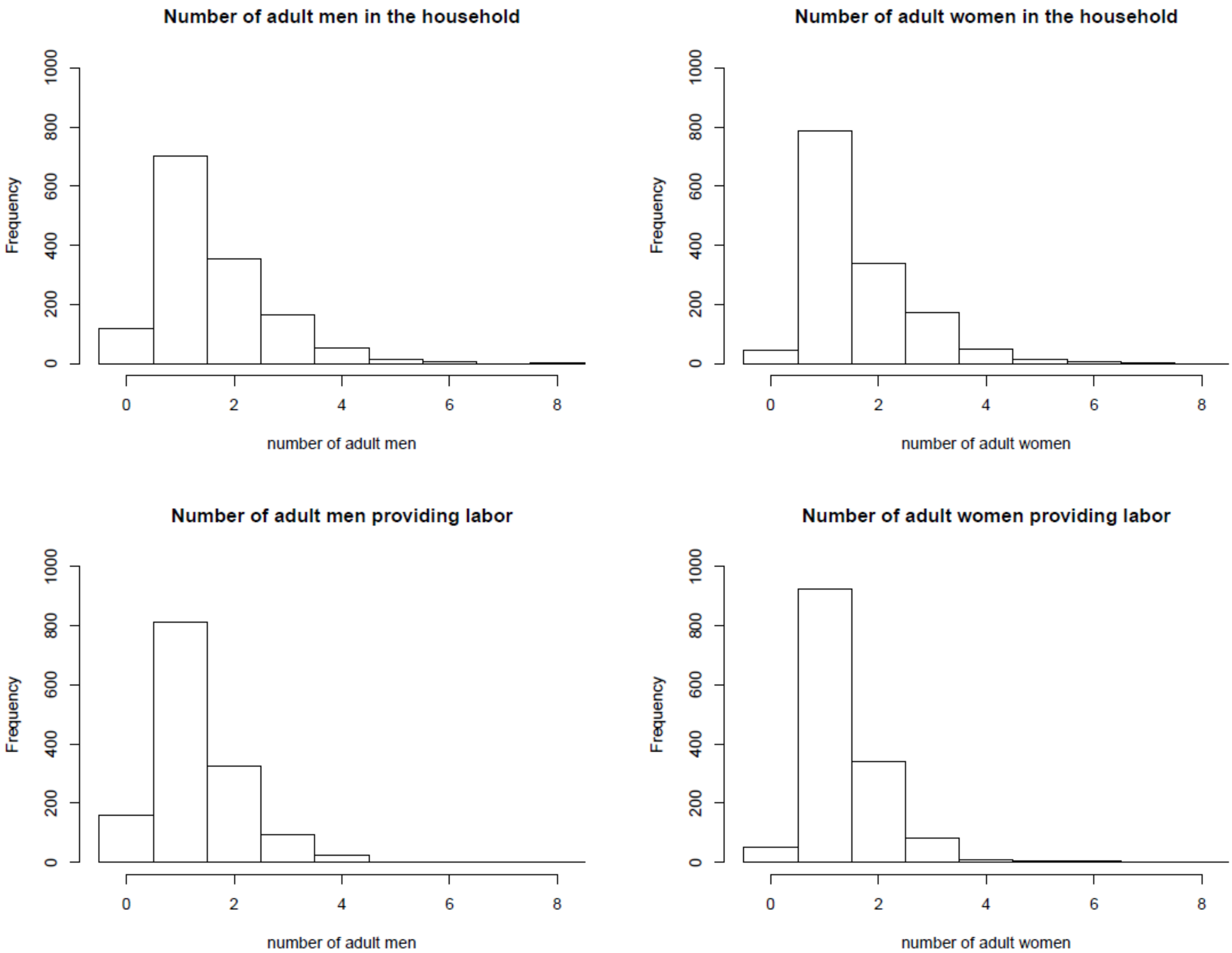


Figure 7: Number of men and women in the household and providing labour

Note: Adult men and women providing labour pertains to the household and performed their work in the 12 months prior to the survey.

The most frequent household composition was one adult man and one adult woman. Also, most frequently there were one man and one woman from the household working on the farm.

Although 71,2 % of the household heads were men, there were slightly more labour in the farms provided by women than by men as per above histograms.

The interview continues in recording the persons digging the holes and planting the trees.

In 79,3% of the cases, this was the surveyed farmer her/himself. Those 79,3% can be split in 48,8% female, 28,0% male and 2,5% unknown. (The unknown is again due to the fact that the survey did not collect the gender of the respondent and this has to be deducted from the relationship with the household head when possible). In 24,6% it was (also) his wife & in 5,1% of the cases it was (also) her husband which was doing the digging and planting of the trees. In 5,2% of the cases a daughter was also involved and in 19,9% a son. The grandmother was involved in 2,3% of the cases while the grandfather in 8,1%. In 0,4% also the father gave his help and in 4,9% the mother. The household head was almost never involved as it scores 0,2%! Summarizing: adult women were mostly digging the hole, expect in the case of the son or grandfather which were more involved than their feminine counterpart.

4,9% of the households said hiring personal for planting the trees, it was mainly adult men from which one third were young adults from 18 to 30 y.o. Almost no hired women and elderly persons and very few children.

For the other activities such as manure/ mulch/ fertilizer application, watering, fencing and pruning, the gender distribution kept the same over the generations having adult women and mothers more active than men, supported mainly by grandfathers and sons.

The involvement of the household head changed from hole digging and tree planting (0,2%) as already mentioned above, pruning 0,3%, watering 5,3%, manure application 16%, fencing 46,2%, mulch application 50,2%, synthetic fertilizer application 93,6%.

The average time for manure application was 45,5 min (median 30 min), for mulch application 37,7 min (median 30 min), for fertilizers 27,6 min (median 30 min), watering 46,8 min (median 30 min), fencing 62,2 min (median 45 min), pruning 30,4 min (median 20 min). Those values do not include the farmers who responded '0 min' who did not perform the activity. Pruning took place in average six times per year.

For 70,1% of the households, tree planting and tree management increased the time spent working on the farm, for 24,6% of the households it stayed the same, and for 5,3% it decreased the farm working time.

Food security & migration

Then the interview continued asking the households about their situation concerning food security.

- 1017 households (71,8%) expected that the seasonal harvest (April/ May rains) will be enough to cover the household consumption's needs and 399 households did not (28,2%). From those 1017 households, 566 households (55,7%) expected surplus and 451 did not (44,3%).
- Then the 399 households were asked how they expect to cope with their consumption deficit, they could give several answers: 99,7% mentioned that they would buy food at the market, 28,3% of the farmers would sell assets, 15,8% expected to receive money from relatives/friends, and 12,0% were looking forward to receive government assistance or food aid.
- 26,0% of the households received government assistance or food aid in the last 5 years and 18,6% in the last 12 months.
- 65,8% of the households were worried to not have enough food to eat in the past 12 months. 60,0% did not always eat healthy or nutritious food in the last year and 66% had times where there were only few food options. 51,5% of the households had to skip meals at least once due to lack of money or resources during the last 12 months, 56,4% had to eat less meanwhile 30,4% could not eat during a whole day.

About the migration background following information can be summarized:

- 49,7% of the interviewed farmers were born in their actual village and 49,1% had their parents born also in that village. The median time that the farmers were working on their farm was 20 years (1^{st} quartile 13 years and 3^{rd} quartile 30 years)
- 33,3% of the household had household members, who permanently

lived and earned their living elsewhere. 13,6% planed/were expecting to do so in the following 5 years.

- Concerning the members of the household, who already migrated elsewhere, the average number of men was 1,45 and women 1,61. For the future it would be additionally an average of 0,76 for men and 0,97 for women. So that women were slightly more subject to migration.

Access to land and investment priorities

Then each household mentioned the area of land they had at disposition during the last 12 months. The data provided in square meters, acres has been transformed to hectares for better comparison. The total land surface was 6267 hectares, so considering 1416 households, the average land surface per household was 4,4 hectares. 81,9% of the households had a surface of 5 hectares or less.

The following histogram (Figure 8) is split in two parts. First, it represents the households which had access to 7 hectares or less, which covered 87,4% of the households and then those with more than 7 hectares.

Then, Table 1 gives the survival rates depending on the land surface the farmer has access to.

Farm land surface	up to 1 ha	>1 up to 2 ha	>2 up to 3 ha	> 3 up to 4 ha	> 4 up to 5 ha	> 5 up to 10 ha	>10 up to 20 ha	> 20 ha
Number of trees that survived	1053	2069	1702	606	593	643	543	175
Number of trees that did not survive	2163	3009	2127	557	618	558	798	303
Survival rate	32.7%	40.7%	44.5%	52.1%	49.0%	53.5%	40.5%	36.6%

Table 1: Tree survival rate depending on land surface of owner

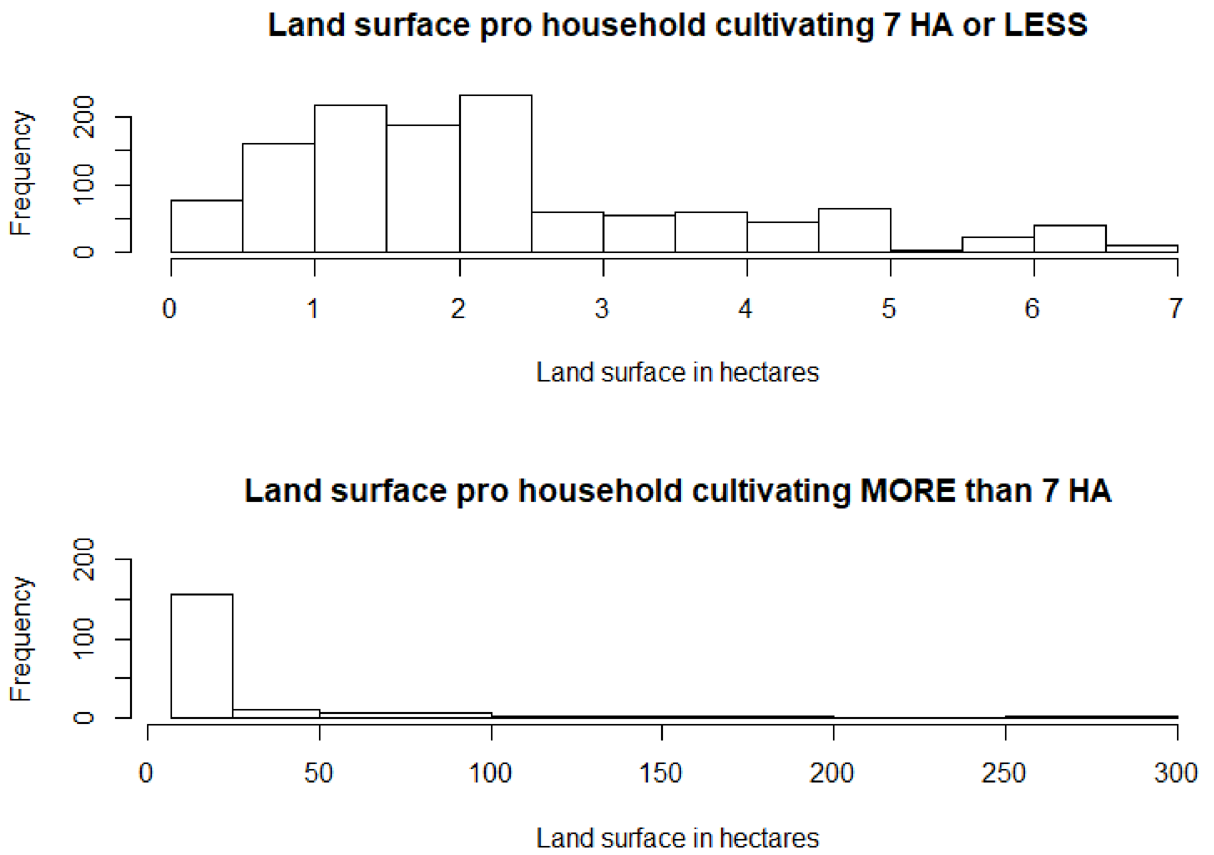


Figure 8: Surface of land accessible to the households

Marginal farmers (below 1 ha) performed worst (32,7%), followed by farmers with more than 10 hectares (36,6-40,5%) and then the smallholders with up to 2 hectares (40,7%). The best survival rate were reached by farmers, who had access from 2 ha to 10 ha (44,5-53,5%).

1279 households were owners of at least of part of the land they had access to during the previous 12 months, 80 households rented at least a part of the land, 14 households borrowed it and 3 households had other conditions.

The 1279 owner households answered the question of documentation of land tenure and 988 households confirmed a title deed (77,2%), 228 an allotment letter (17,8%) and 63 others (4,9%), the latter mainly related to a heritage.

1253 households answered that their owned land can be securely used as long as they would need it (98%), 26 households answered that they cannot. In case of the rented land it was 53 from 80 households (66%) and in the case of borrowed it was 8 households out of 14 (57%).

148 households mentioned plots far from their home (median value of the distance is 3 km) against 1268 households where the plots were nearby.

Farmers are optimistic. Although 56,5% had experienced a decline in crop production in the last five years, 68,7% were expecting an improvement in the next five years. 34,8% had experienced an improvement in the last five years and 8,7% no change. 19,6% were expecting a decline in the next five years and 11,7% no change.

Then the farmers have been asked what they would do if they would have 25.000 KES (Kenyan shillings) which is equivalent to 215 €:

- some farmers would invest in their farm: 36,4% would buy more livestock, 16,9% would buy trees, 8,4% would buy land;
- 35,7% would open a business or a shop;
- 19,6% would use it for them or their children to go to school;
- 12,3% would improve their house, 0,4% would move to another place.

Then the farmer had the possibility to give his own additional comments where a lot of ideas came out such as:

- business: kiosk, vegetable shop, cereal shop, clothes, handicraft, hairdresser salon, tailor, hotel, bookshop, tree nursery, improved storage sacks;
- for the farm investments: manure, certified seeds, chemicals and fertilizers, water harvesting tank, borehole drilling, farm pounds, water pipes, terraces, zai pits (Figure 9), ploughing bulls, donkey to fetch water, hire labour, hire a tractor for ploughing, a poultry house, plant watermelons, install fencing;
- buy a solar panel, improve the bicycle;

- buy food, medication, home utensils and chairs;
- learn at a driving school, learn hairdressing, record songs.

Photo: Tunde Amole

Source: Sanou et al, 2018

Figure 9: Digging zai pit

Also, the farmers were asked about land restoration/ land management options that they would be interested in implementing on their farms. The responses can be summarized as follow:

- cover crops, (Napier) grass covering, (fruit) tree planting, sisal planting, conservation agriculture (= minimum soil disturbance/ soil organic cover/ species diversification according to FAO (2017a)), manure, mulch, crop rotation, crop variety, vegetable/ fodder cultivation, avoiding deforestation;
- farm pound, water harvesting, reducing distance to water;
- check dam (to reduce water velocity), terraces, fencing, gabions, trenches, contour bundings/ farming/ ploughing, fanya juu[5], soil & water conservation techniques, wind breaks;

5 Terrace technique, means "throw the soil up" in Kiswahili

- restore dry land, natural farm regeneration, fallow, Farmer-Managed Natural Regeneration (FMNR);
- apiculture, controlled grazing, pasture establishment, less livestock, poultry/ dairy farming, improved livestock;
- grafting/pruning tree, horticulture.

The farmers have been asked to give some remarks. The additional information provided by those remarks can be summarized as follow:

- in the drought years, there is food shortage due to low yield but this year (2018), there was a surplus;
- farmers asked for food aid during drought year nevertheless they said that food security had improved;
- market for selling surplus was needed, the middlemen were seen as problematic;
- farmers requested new seedlings due to non-survival, hybrid seeds, drought resistant crops, farm inputs such as fertilizers, pesticides/ chemicals, agrobags;
- farmers praised Drydev (the Drylands development programme[6]) for the knowledge they provided;
- request for education on crop/seedlings diseases, pesticides, how to store surplus, climate smart agriculture;
- trees enhance micro-climate, zai pits are often mentioned as improving yields;
- irrigation was seen as a potential solution, boreholes/ dams were needed;
- mentioned crops were green grams, maize, sorghum, watermelons.

6 The Drylands Development Programme (DryDev) is an initiative funded mainly by the Netherlands (2013-2019), with the World Agroforestry Centre (ICRAF) as the main implemeting actor. https://drydev.org/

Factors of tree seedling survival

This sub-chapter is dedicated to give some elements to understand the tree seedling survival rate on both years.

The first focus is on the tree planting dates including an addition with the precipitation data of the two years of the project. Then in a second paragraph the different species with their locations, sub-counties and niches will be studied. Finally, tree management techniques such as planting hole size, application of manure or mulch, watering, pruning, fencing and presence of shade will be analysed before heading to the categories mentioned by farmers themselves for the non-survival.

Planting date & climate

The planting date informs about the approximate age of the trees at the time of the survey, thereby providing information on the suitability of the planting period.

'Tree planting data 2017' had 14.804 tree entries: 84 trees have been planted in 2015 or before (0,6%), 14.154 trees have been planted in 2016 (95,6%) and 566 trees have been planted in 2017 itself (3,8%). The trees planted in 2017 have been planted mainly in January, May, June and July.

The main period of planting in 2016 was October, November and December. 14.071 trees have been planted in this three-months period, that represents more than 95% of the planted trees reviewed in the following year.

Figure 10 is the graphical representation through histograms, for better comparison both histograms have the same scale in the Y-axis.

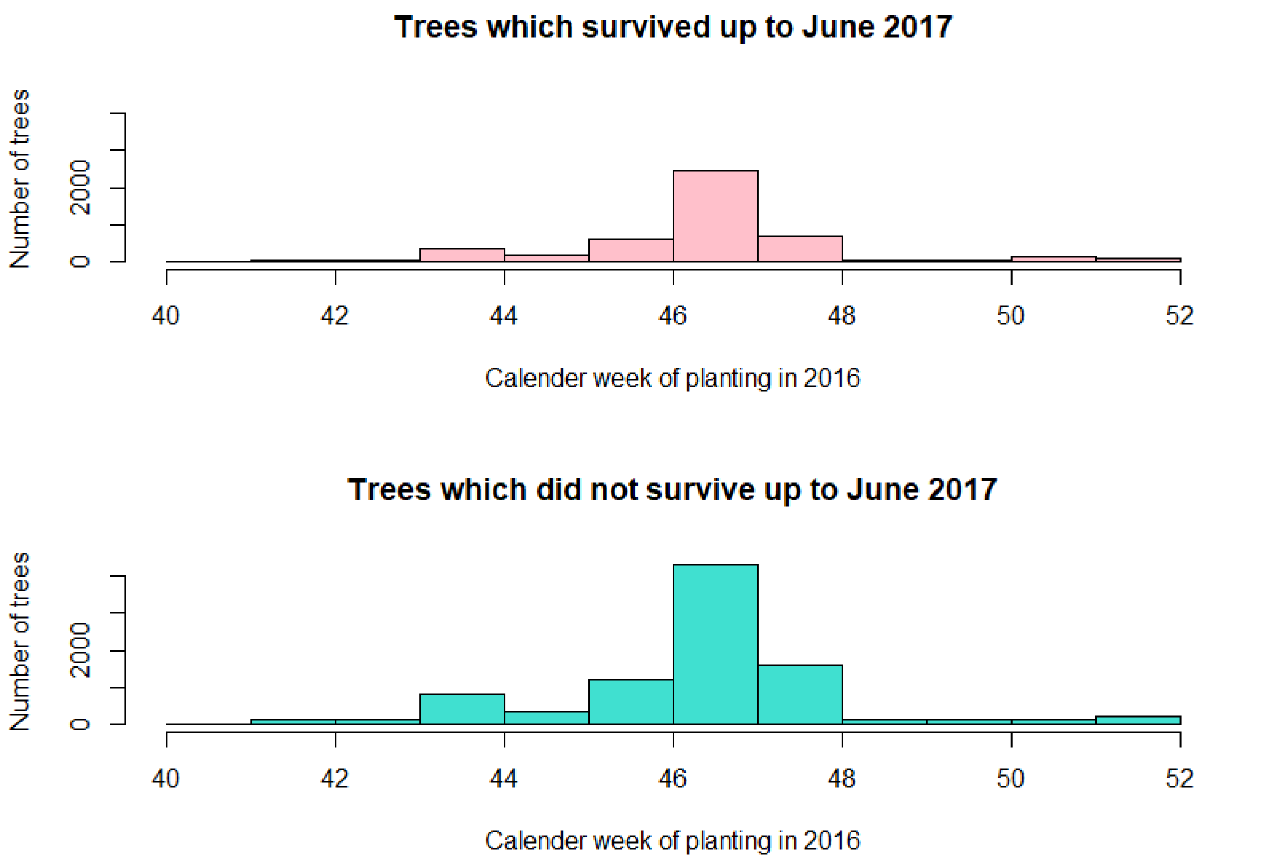


Figure 10: Tree planting date & survival - October November December 2016

The calendar weeks are defined as follow: cw 41 being the week from 10th to 16th October 2016 up to cw 52 being the week from 26th to 1st of January (here only the values up to 31st December 2016 are considered). The majority of the trees have been planted in week 47, which is from 21st to 27th of November 2016. In the figure, the week number is written at the end of the corresponding bar (usual 'R Studio' representation).

Based on a visual comparison of the planting weeks, there is no recognizable difference in distribution between trees that survived and those which did not survive.

The second year of the project is under the database 'Tree planting data 2018': 17.423 entries had a planting date (from 17.517 planted trees).

There were 7 trees, that were planted in 2016 (<0,1%), 17.268 trees were planted in 2017 (99,1%) and 148 trees in 2018 (0,8%). The trees planted in 2018 were planted mainly planted in July 2018, which is part of the driest period of the year.

The main period of planting was October, November and December 2017. 17.259 trees were planted in that period that represent more than 99 % of the trees with a planting date.

Figure 11 is the graphical representation through histograms.

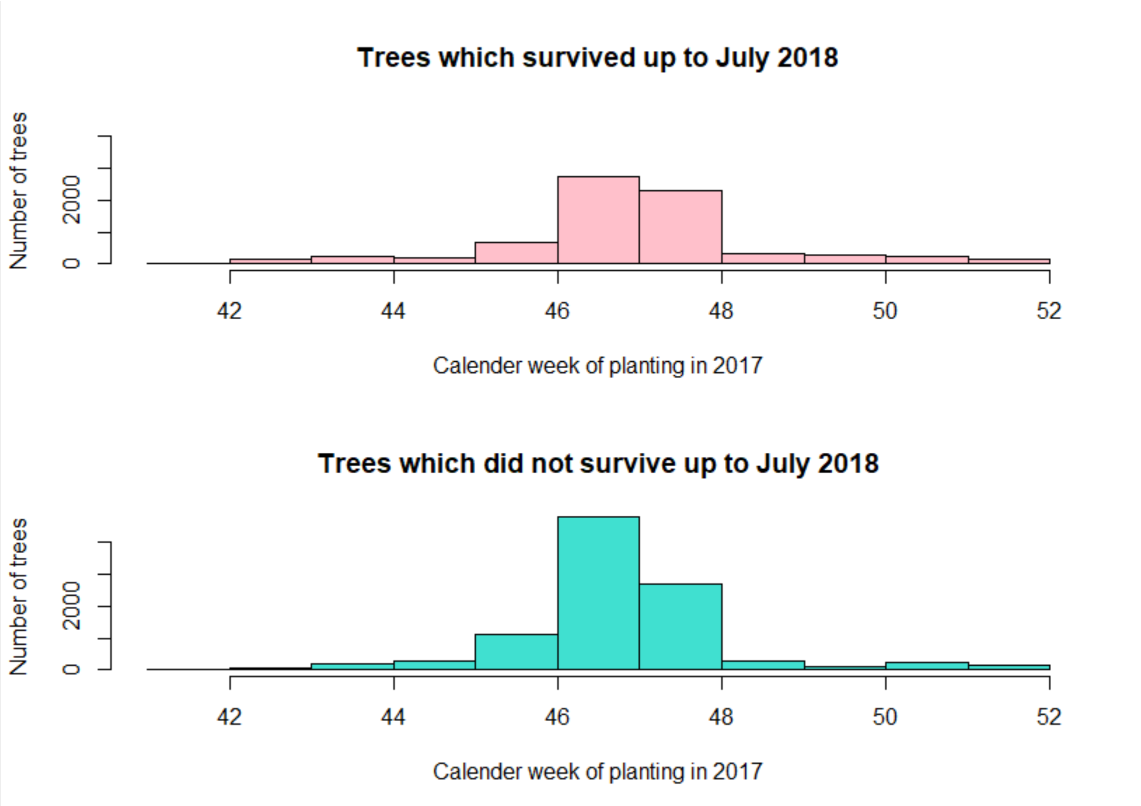


Figure 11: Tree planting date & survival - October November December 2017

The calendar weeks are as follow: cw 42 is from 16th to 22nd October 2017 up to cw 52 which is from 25th to 31st December 2017.

The main planting weeks are weeks 47 and 48, the week 48 (27.11-3.12.2017) has definitively a better survival rate than week 47 (20-26.11.2017).

From worldclim.org (Fick & Hijmans, 2017), the precipitation on both project periods has been generated with a monthly scale (Figure 12 and Figure 13). Only the nine months between tree planting and survey dates are represented, from October to June, the in-between three months from July to September being among the driest. Those two figures confirm that the second year of the project had much higher rainfalls than the first year. The maps are prepared, so that they exactly encompass the seven sub-counties of the project. The map with the location of the sub-counties is in Figure 2 of the 'Material and Method' chapter, the name of the sub-counties are repeated in the first picture of Figure 12 as a reminder.

Then in order to know the rainfall intensity in the three previous years and the year after the project, the precipitation from October to December are represented for the years 2013, 2014, 2015, and 2018 (Figure 14 and Figure 15). Except November 2015, which had rainfall quantity between the values of November 2016 and November 2017, the other values for November were even worst than 2016.

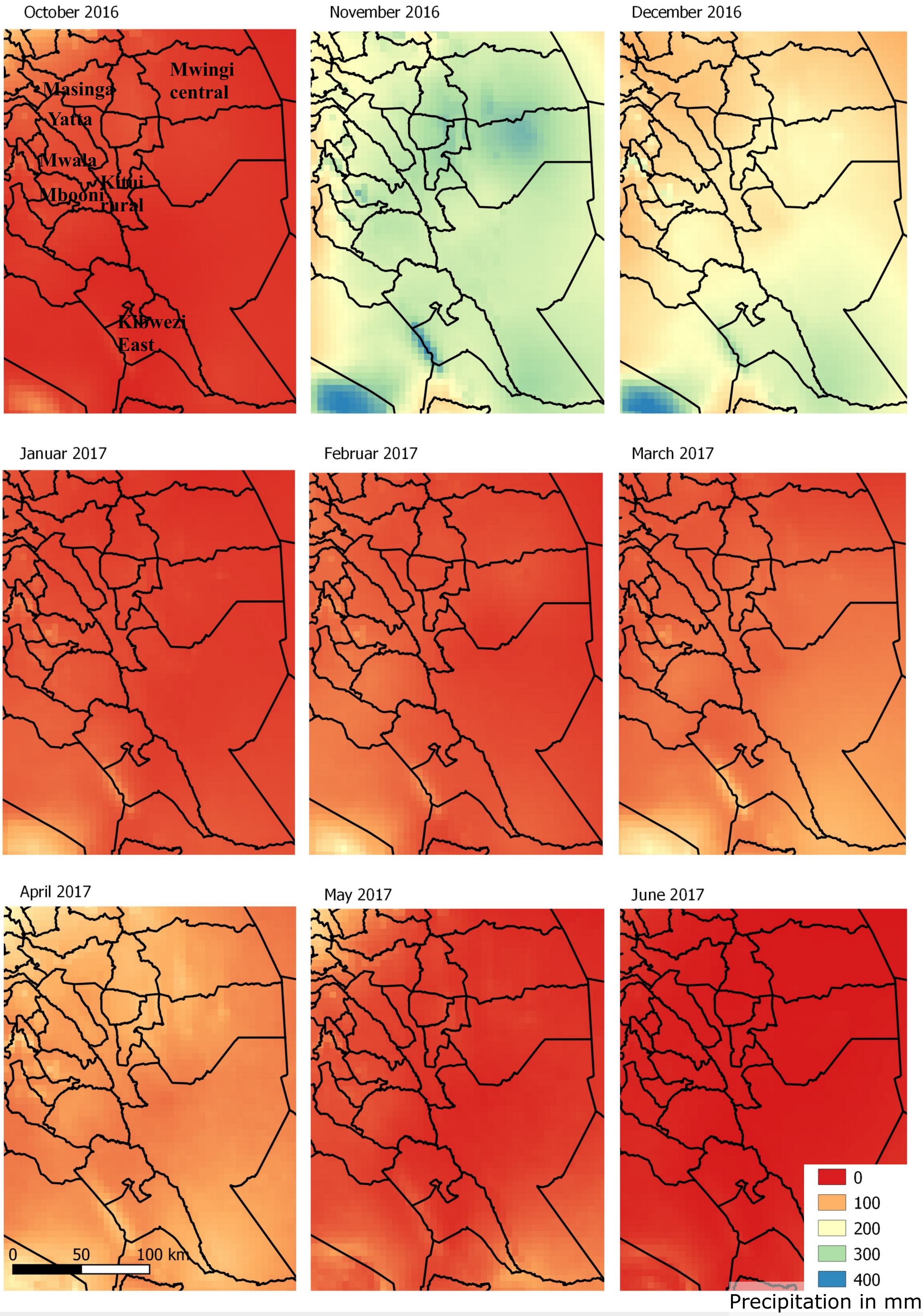


Figure 12: Precipitations per month from 10/2016 to 06/2017 in Kitui, Machakos and Makueni from worldclim.org

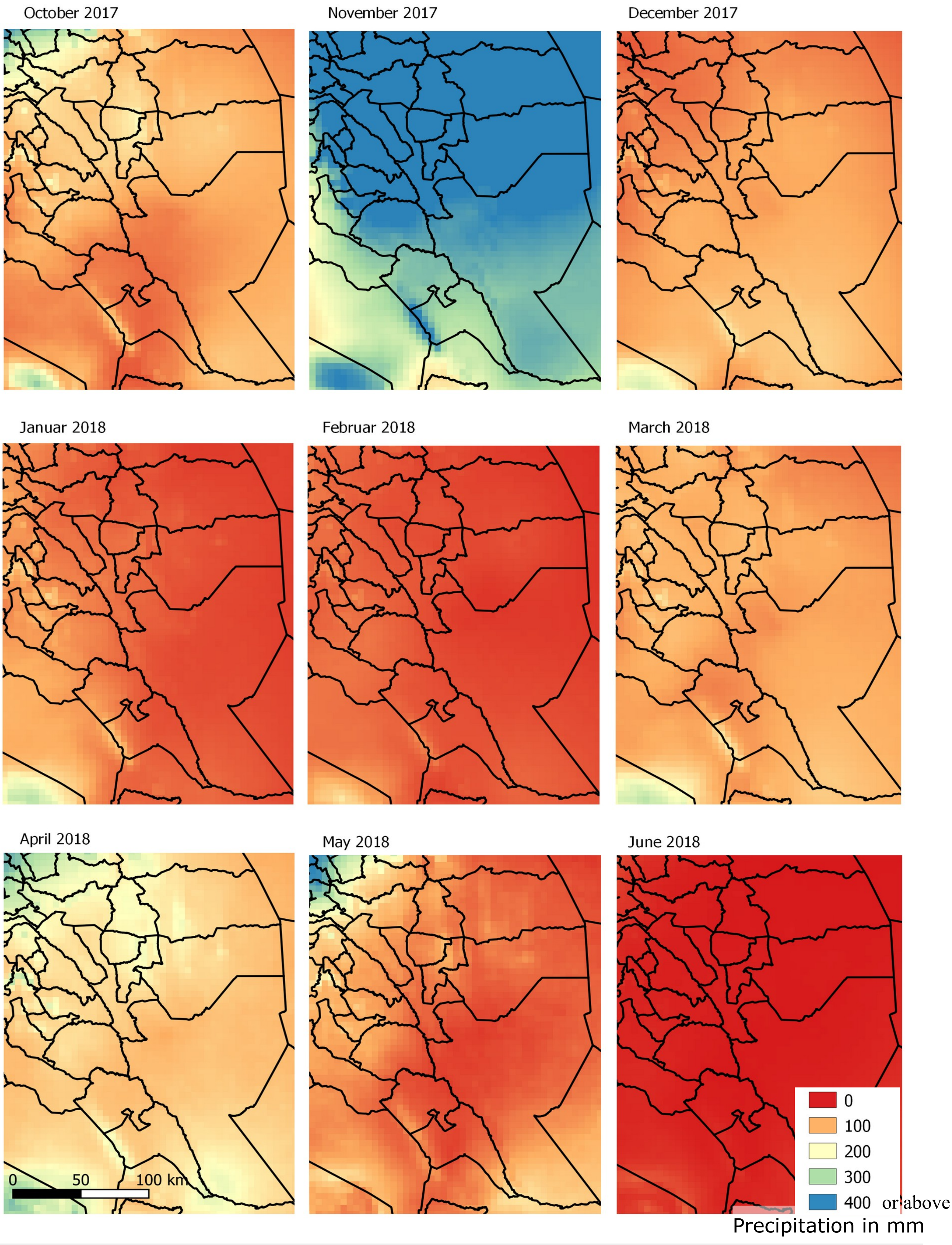


Figure 13: Precipitations per month from 10/2017 to 06/2018 in Kitui, Machakos and Makueni from worldclim.org

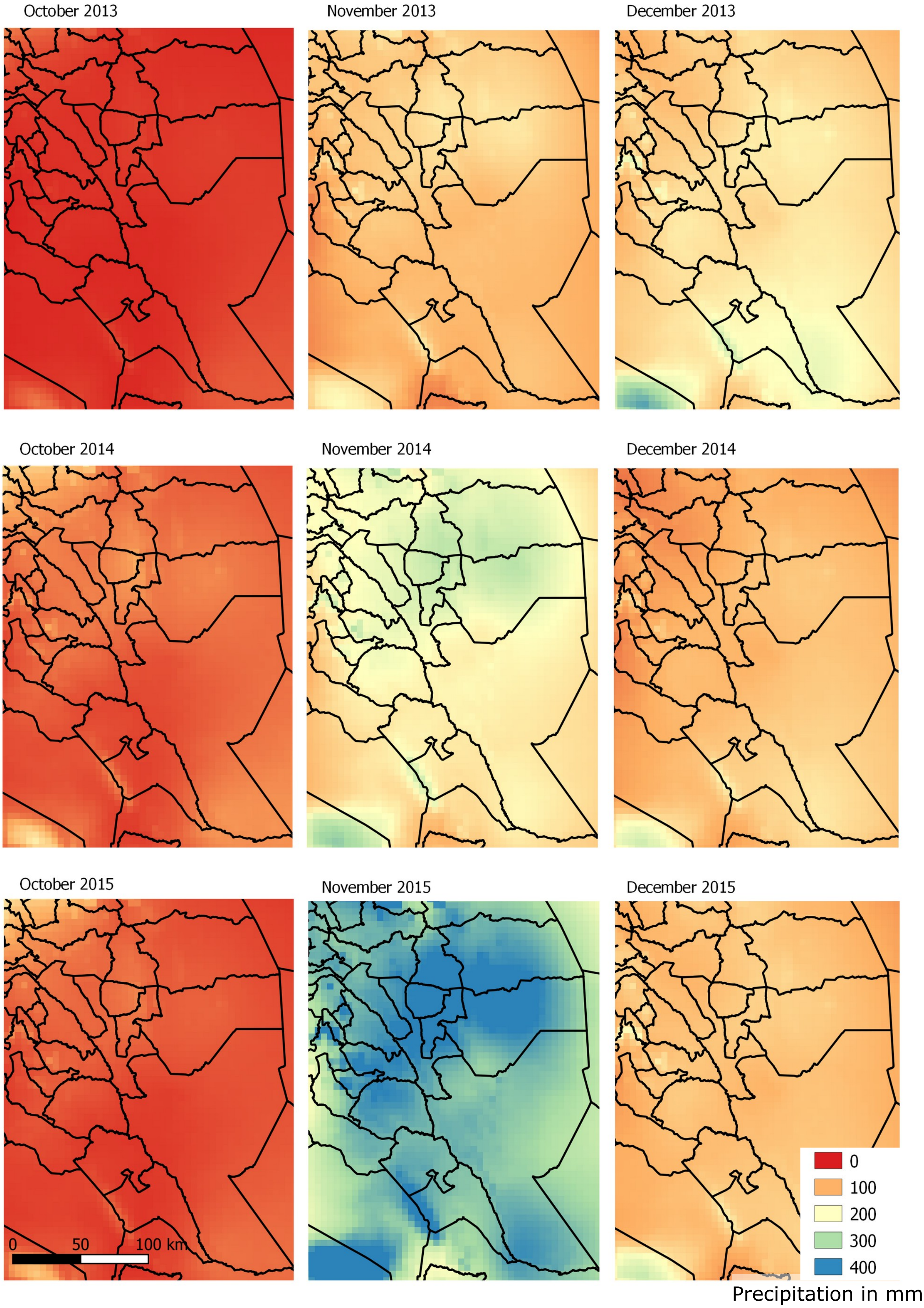


Figure 14: Precipitations per month last three months of 2013, 2014 and 2015 in Kitui, Machakos and Makueni from worldclim.org

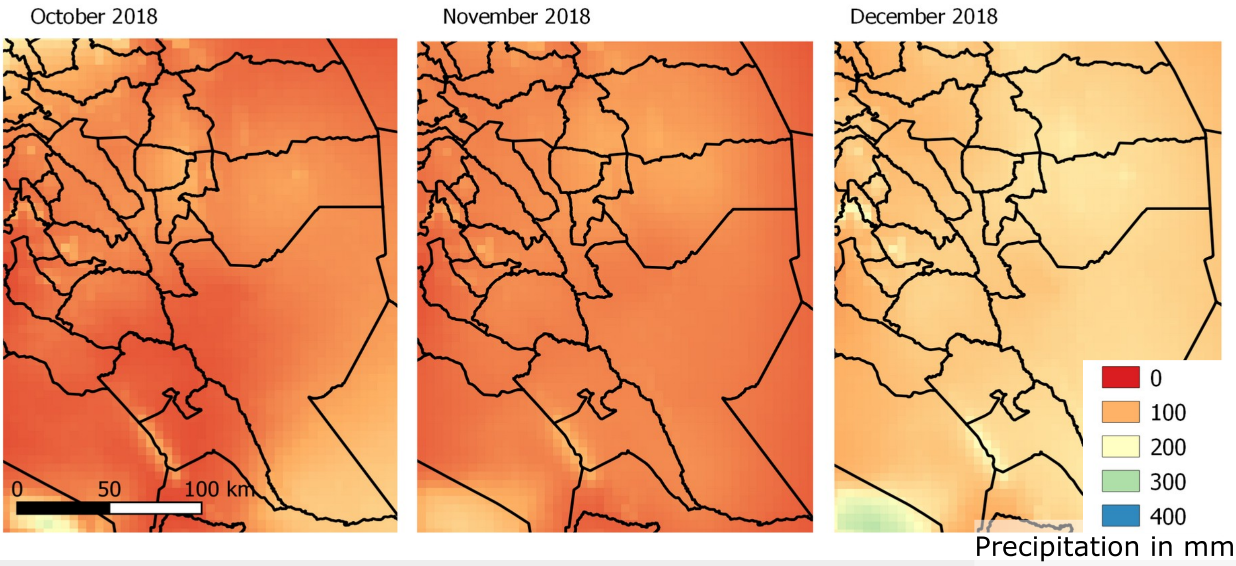


Figure 15: Precipitations per month Oct to Dec 2018 in Kitui, Machakos and Makueni from worldclim.org

An other information from 'Tree planting data 2017' and 'Tree planting data 2018' was the record of the heights and diameters of the different tree species in the two years. The data displayed with the help of boxplots and an XY plots of the tree diameter in function of the tree height can be found in appendix 3.

There are real improvements in the height of the trees, especially *Carica papaya*, *Melia Volkensii* and *Moringa oleifera* moving from a median value of around 50 cm or below in 2017 to median values higher than 1 meter in 2018. The newly introduced *Calliandra calothyrsus* is the highest tree with a mean value of the height of almost 1,5 meters.

The tree diameters also increased also between the survey of 2017 and the survey of 2018 for the majority of the trees. In 2017, the maximum median value of the diameters is 5 cm for the *Carica papaya* being also the wider tree in 2018 but with a median value of 10 cm. Only the *Azadirachta indica* had a smaller median diameter giving it the position of smallest tree in diameter in 2017.

Tree species & location

The tree species had different survival rates that additionally varied between the two years of the surveys.

In the first year of the project, there were six different species: *Azadirachta indica*, *Carica papaya*, *Mangifera indica*, *Melia volkensii*, *Moringa oleifera* and *Senna siamea*. In the second year, there were the same trees species as in the previous year with additionally *Calliandra calothyrsus.*

The quantity of each species for each year and the corresponding survival rate is displayed in Table 2:

	2017		2018	
Species	**Quantity**	**Survival rate**	**Quantity**	**Survival rate**
Azadirachta indica	3169	36.6%	2950	32.5%
Calliandra calothyrsus			221	70.6%
Carica papaya	1574	21.0%	335	47.5%
Mangifera indica	4474	39.3%	7241	43.4%
Melia volkensii	2691	26.7%	3844	40.3%
Moringa oleifera	1220	28.4%	1072	54.0%
Senna siamea	1676	46.9%	1854	45.4%

Table 2: Tree species quantity and survival rate - 2017 and 2018

In 2017, *Senna siamea* had the relative highest survival rate as almost the same number of trees survived than died (46,9%). This is followed by *Mangifera indica* (39,3%) and *Azadirachta indica* (36,6%). *Carica papaya* had the worst survival rate (21,0%), followed by *Melia volkensii* (26,7%) and *Moringa oleifera* (28,4%).

The most often planted tree is *Mangifera indica* (4474 trees) followed by *Azadirachta indica* (3169 trees) and *Melia volkensii* (2691 trees).

A visual representation of those data for 2017 with the help of a bar diagram is represented in Figure 16.

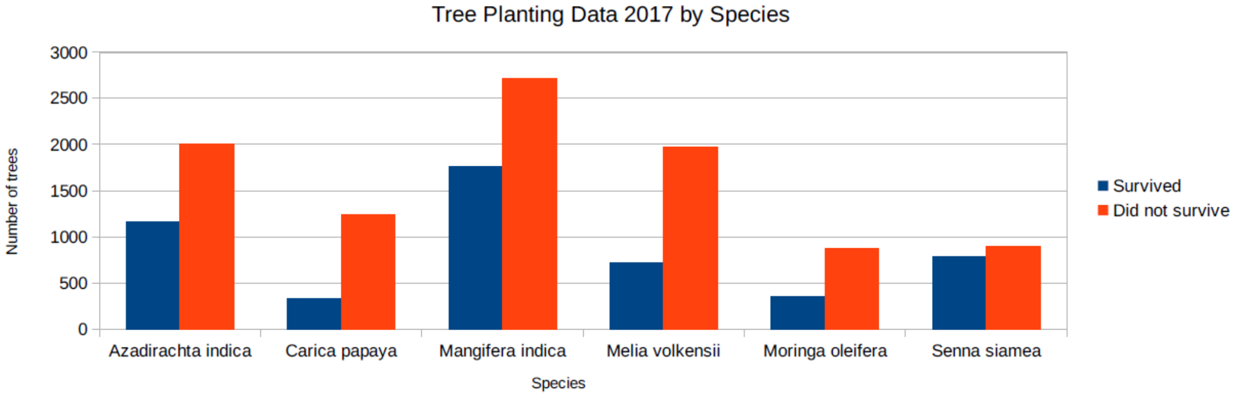


Figure 16: Survival rate by tree species - 2017 survey

The bar diagram is also available for 2018 under Figure 17.

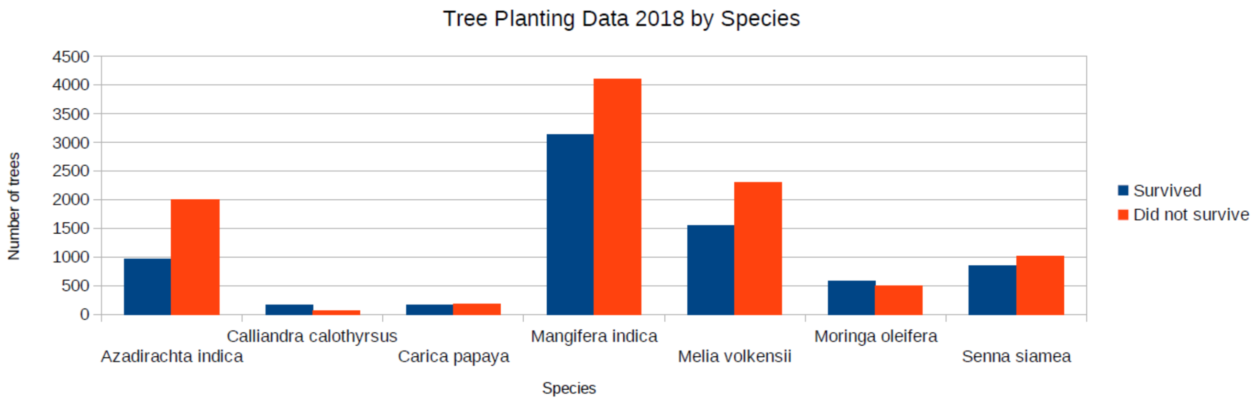


Figure 17: Survival rate by tree species - 2018 survey

In 2018, the newly introduced *Calliandra calothyrsus* had the highest survival rate (70,6%) but there were only few trees planted, 221 trees in total.

The *Carica papaya* has also been planted at a low quantity (335 trees) that could be connected to the lowest survival rate in the previous year which was 21,0% but got improved in this second year to 47,5%.

The *Moringa oleifera* performed better in the 2018 survey increasing from 28,4% to 54,0%, which is almost a doubling of the survival rate. Unfortunately, the quantity of trees is also not too high (1072 trees).

The most commonly planted trees in 2018 are *Mangifera indica* (7241 trees) and *Melia volkensii* (3844 trees), both improved their survival rate from the previous year from 39,3% to 43,4% and 26,7% to 40,3% respectively.

The quantity of planted *Azadirachta indica* reduced slightly comparing it to the previous year (from 3169 trees in the 2017 survey versus 2950 trees in 2018), also with a decline of the survival rate from 36,6% to 32,5%.

Senna siamea which was the best performer in 2017, kept a similar survival rate of 45,4% (instead of 46,9% in the previous year), also the quantity of planted trees stayed relatively similar (1854 trees versus 1676 trees during the previous year).

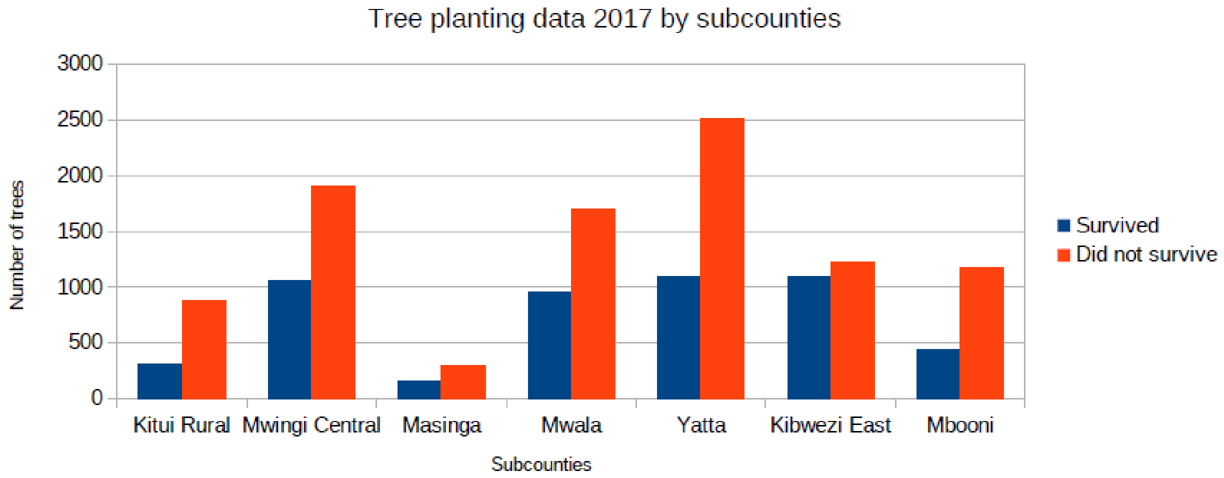
This paragraph depicts the situation in the different sub-counties.

Table 3 provides the information of quantity of trees in counties and sub-counties with the corresponding survival rate.

		Tree planting data 2017			Tree planting data 2018		
Counties	Sub-counties	Quantity	Survival rate		Quantity	Survival rate	
Kitui	Kitui Rural	1181	25.6%	32.8%	1333	40.4%	53.4%
	Mwingi Central	2962	35.7%		4159	57.6%	
Machakos	Masinga	447	34.5%	32.9%	304	31.3%	32.2%
	Mwala	2659	36.0%		1196	43.0%	
	Yatta	3615	30.4%		5314	29.9%	
Makueni	Kibwezi East	2322	47.2%	39.0%	3683	33.9%	43.3%
	Mbooni	1604	27.2%		1507	66.3%	
	NA	14	0.0%		21	42.9%	

Table 3: Survival rate by sub-counties for the 2017 and 2018 survey

At first, Figure 18 depicts the distribution in the first year:



Kitui county | Machakos county | Makueni county

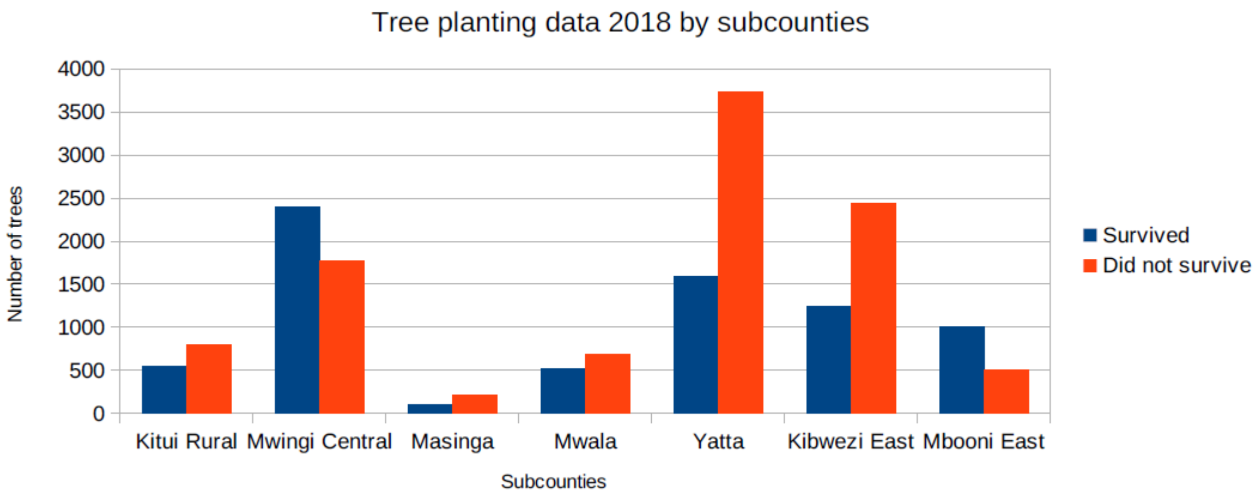
Figure 18: Planted trees by sub-counties & survival – 2017 survey

Kibwezi East (Makueni) had the higher relative quantity of trees that survived with a survival rate of 47,2%. Worst survival rates were reached by Kitui Rural (25,6%) and then Mbooni (Makueni) (27,2%). Mwala, Mwingi Central (Kitui), Masinga and Yatta (Machakos) had middle survival rates ranging from 36,0% down to 30,4%.

The histogram (Figure 18) also shows that Yatta and Mwala (Machakos) and Mwingi Central (Kitui) were the sub-counties where more trees have been planted (more than 2500 trees per sub-county).

During the second year, the survey took place in the same sub-counties, only 'Mbooni' got called 'Mbooni East' but theya re both surveying the same ward called Kalawa.

The survival rate per sub-county in 2018 is depicted in Figure 19.



Kitui county | Machakos county | Makueni county

Figure 19: Planted trees by sub-counties & survival – 2018 survey

The tree planting distribution changed slightly as Mwala (Machakos) got few less trees surveyed than in the previous year (1196 versus 2659 trees in the previous year). Yatta (Machakos) and Mwingi Central (Kitui) are the best represented with 5314 and 4159 trees respectively, followed by Kibwezi East (Makueni), 3683 trees.

In 2018, Mbooni (Makueni) and Mwingi Central (Kitui) got the best survival rate: 66,3% and 57,6%. Then Mwala (Machakos) and Kitui rural are following with survival rate of 43,0% and 40,4% respectively. The places with lowest rates are covered by Yatta & Masinga (Machakos) 29,9% & 31,3% and then Kibwezi East (Makueni) 33,9%.

The performance of the sub-counties between the two years does not show a tendency as some sub-counties (Kitui Rural, Mbooni, Mwala, Mwingi Central) improved and one got worse (Kibwezi East). Also, there is no common trend within a county that can be recognized.

Then it raises the question if the trees have been planted homogeneously in the different sub-counties (Figure 20 and Figure 21).

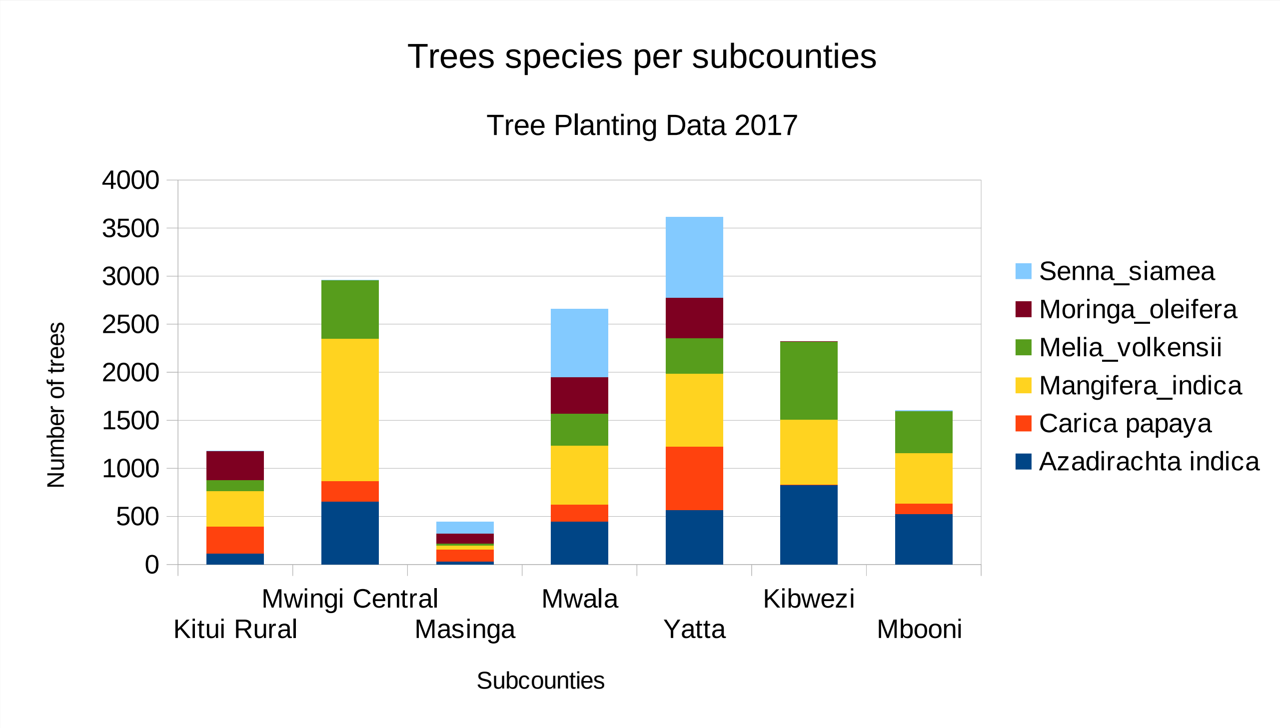


Figure 20: Distribution of tree species in the sub-counties - 2017

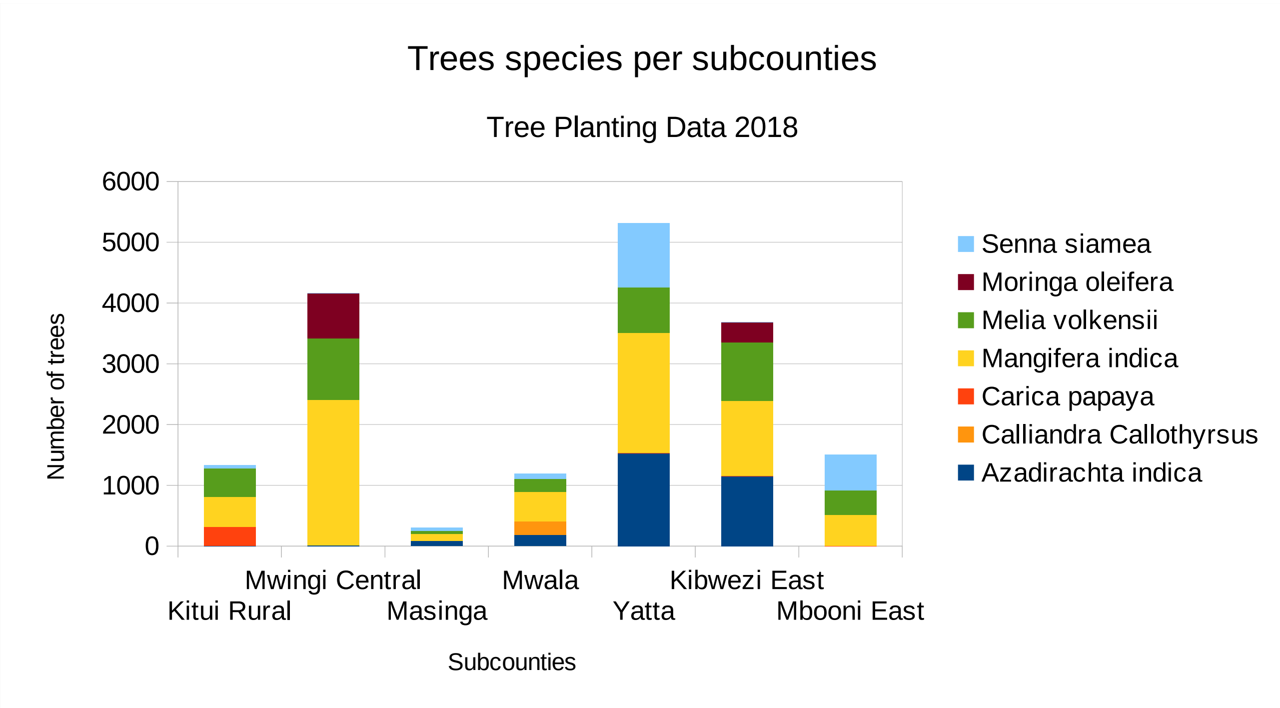


Figure 21: Distribution of tree species in the sub-counties - 2018

Kitui county:

Kitui Rural had a focus on *Mangifera indica*, *Melia volkensii* and *Carica papaya* with *Moringa oleifera* and *Azadirachta indica* only in 2017 and few *Senna siamea* from the 2018 survey.

Mwingi Central: the main trees were *Mangifera indica* and *Melia volkensii*. In 2017 additionally *Azadirachta indica* and *Carica papaya* were reviewed meanwhile in 2018 it was *Moringa oleifera*.

Makueni county:

Kibwezi East reviewed in 2017 mainly *Azadirachta indica*, *Melia volkensii* and *Mangifera indica* adding *Moringa oleifera* and few *Senna siamea* in 2018.

Mbooni: Trees were mainly *Mangifera indica* and *Melia volkensii* with additionally *Azadirachta indica* and *Carica papaya* in 2017 and *Senna siamea* in 2018.

Machakos county:

Masinga is the less represented sub-county in both years and uses all kind of trees.

Mwala: in 2017 all tree species were represented, meanwhile in 2018 there were much less trees planted with focus on *Mangifera indica*, *Melia volkensii*, *Azadirachta indica*, *Senna siamea* and *Calliandra callothyrsus*.

Yatta: *Mangifera indica*, *Azadirachta indica*, *Senna siamea* and *Melia volkensii* are the main trees in the 2018 survey. In 2017 there were also *Moringa oleifera* and *Carica papaya*.

The tree distribution was very different for each sub-county and varied between the years.

Then the altitudes of the plots were automatically recorded by the device of the enumerators in the second year and values are represented in a boxplot (Figure 22):

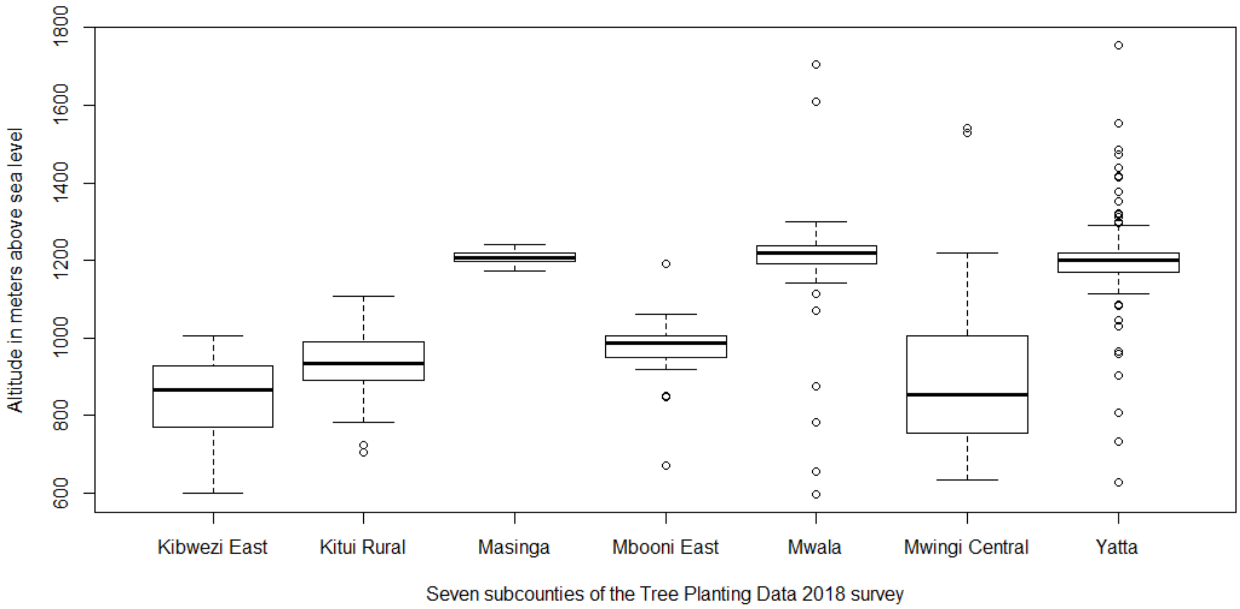


Figure 22: Boxplot altitudes of household plots differentiated by sub-counties

Note: Following outliers have been taken out for better representation as they may be wrong entries or distorting the graph: Mwala 2816,8 m & 260,1 m, Kitui Rural 422 m & Mbooni East 0 m.

Masinga, Mwala, and Yatta with median values of the altitude around 1200 m are all located in the Machakos county.

The sub-counties of Kitui (Kitui Rural and Mwingi central) as well as the sub-counties of Makueni (Mbooni East and Kibwezi East) have a median altitude between 800 & 1000 meters above sea level.

The survival rate for the different species above 1100 m above sea level has been compared with the survival rate of the species at 1100 m or below (Table 4).

The survival rate is always higher for altitude lower than 1100 m. *Carica papaya* cannot be considered as conclusive as only 6 trees have been planted at 1100 m or below which makes the percentage of 83% for the survival rate not robust.

Altitude	Above 1100 m		1100 m or below	
Species	**Quantity**	**Survival rate**	**Quantity**	**Survival rate**
Azadirachta indica	1739	28.4%	1211	38.3%
Calliandra calothyrsus	221	70.6%	0	N.A.
Carica papaya	6	83.3%	329	46.8%
Mangifera indica	2508	33.9%	4733	48.4%
Melia volkensii	979	21.3%	2865	46.8%
Moringa oleifera	8	37.5%	1064	54.1%
Senna siamea	1171	37.9%	683	58.3%

Table 4: Tree quantities and species survival rate for altitudes above and below 1100m – 2018 survey

The place, within the farm, where the tree is planted is called 'Niche' in the interviews and is the subject of this paragraph.

Different types of niches have been differentiated:

- home compound: area around the house, usually fruit, shade or ornamental trees and often in combination with farm animals (Reppin et al, 2020).

- external boundary: building a hedgerow, trees are separating the farmer's plot or farm from other areas. As mentioned in Kurauka (2015), trees are used to protect the home compound, the home garden or pastures from humans and animals.

- internal boundary: hedgerow inside the plot/ farm, that can for instance separate different land use within the farm (Reppin et al, 2020).

- along terraces: for slope areas

- woodlot: areas with high density of trees, mainly dedicated to timber or fuel-wood production (Reppin et al, 2020).

- scattered in crop land: trees are on the same plot as crops

The survival rate results are displayed in Table 5:

	2017		2018	
Niche	Quantity	Survival rate	Quantity	Survival rate
Home compound	4539	35.8%	4539	39.4%
In boundary	2158	33.3%	2158	49.0%
Ex boundary	832	35.8%	832	39.3%
Along Terraces	2577	36.4%	2577	48.2%
Woodlot	559	34.0%	559	39.4%
Scattered	3914	31.3%	3914	38.2%
Other	559	34.0%	559	44.3%

Table 5: Tree quantities and survival rate by niche - 2017 & 2018

The results of the first year did not show a big difference between the different niches, as they had similar tree survival rates. The 'scattered in crop land' niche was the worst location with 31,1% survival rate meanwhile 'trees along terrace' got the best value, 36,4%. The external boundary niche leaded to a slightly lesser survival rate than the internal boundary niche.

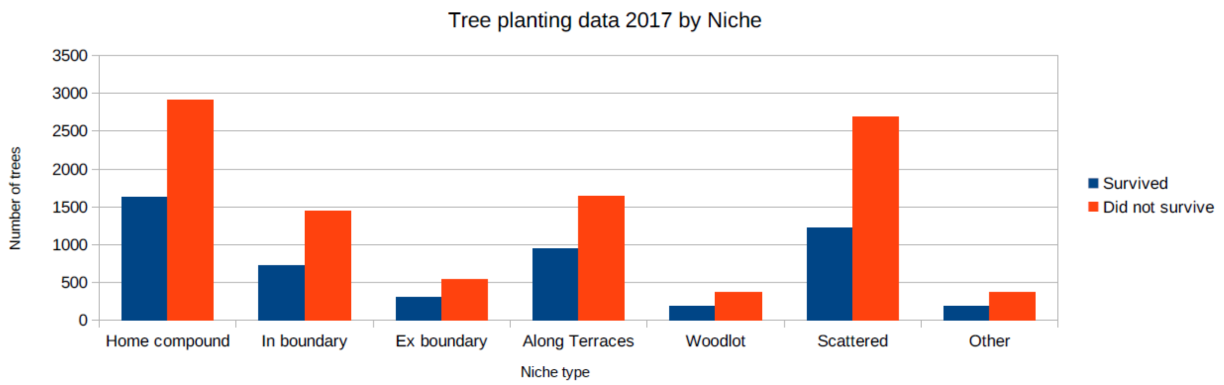


Figure 23: Bar graph tree survival by niche type - 2017

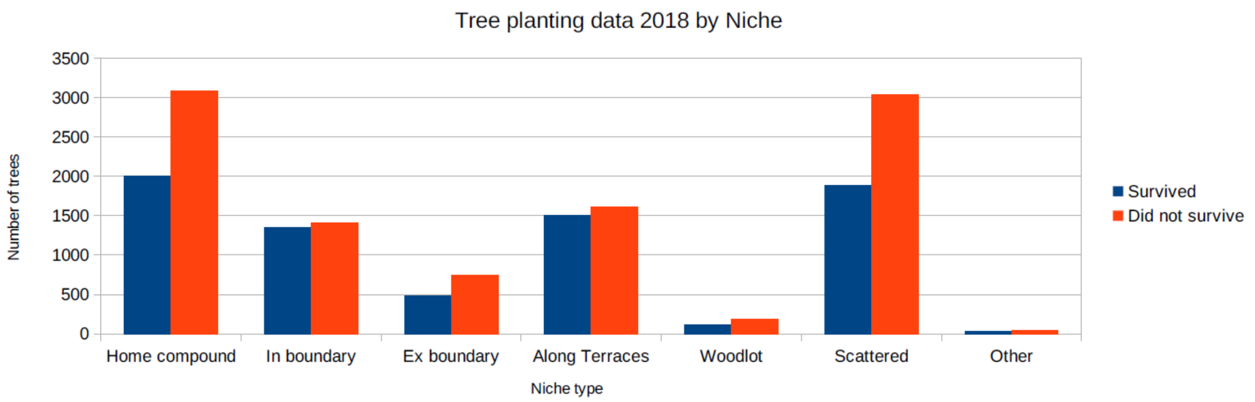


Figure 24: Bar graph tree survival by niche type - 2018

From the bar graphs (Figure 23 and Figure 24) it can be recognized that 'home compound' and 'scattered in crop land' were the most frequent locations.

In 2018 all niches increased their survival rate as this was a better year. There were more disparities in the tree survival rate as 'home compound', 'external boundary', 'woodlot' and 'scattered in crop land' had a survival of 38-39%. 'Internal boundary' and 'Along terrace' on the other hand reached values of 48-49%. The 'others' category contains for instance some trees which have not been planted (28 trees from 79 'others' got this comment).

There were no rules for farmers while choosing the tree species or tree planting niches, households could receive seedlings of different species in the same year and plant them in different types of niches.

Also the quantities of tree seedling per households varied (Figure 25), 21, 14 and 7 seedlings being the most frequent quantities received by the farmers.

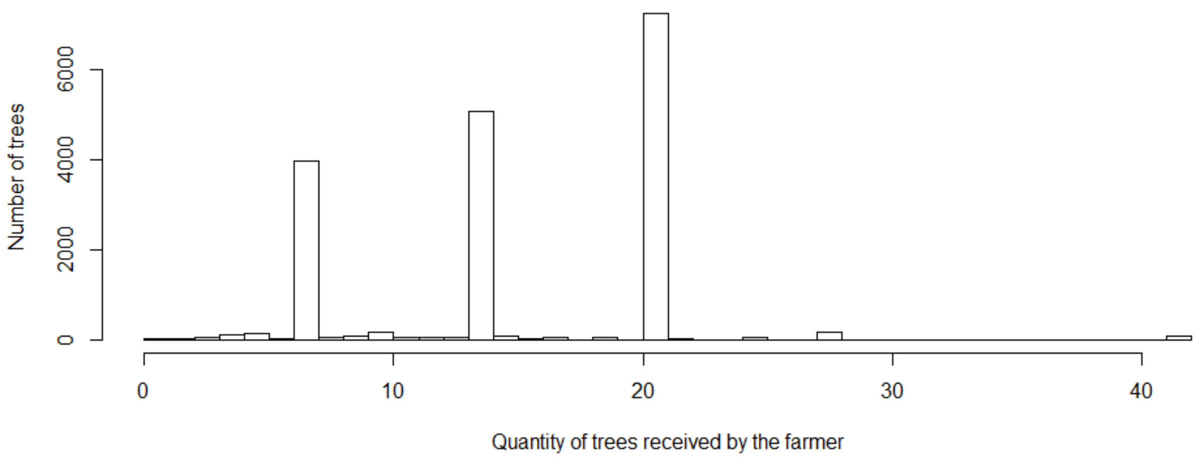


Figure 25: Distribution of tree seedling quantity per households - 2018

The survival rate has been calculated considering depending on the number of trees received by the farmer and the corresponding linear regression line has been represented (Figure 26), nevertheless the line is relatively straight so that no robust conclusion can be drawn.

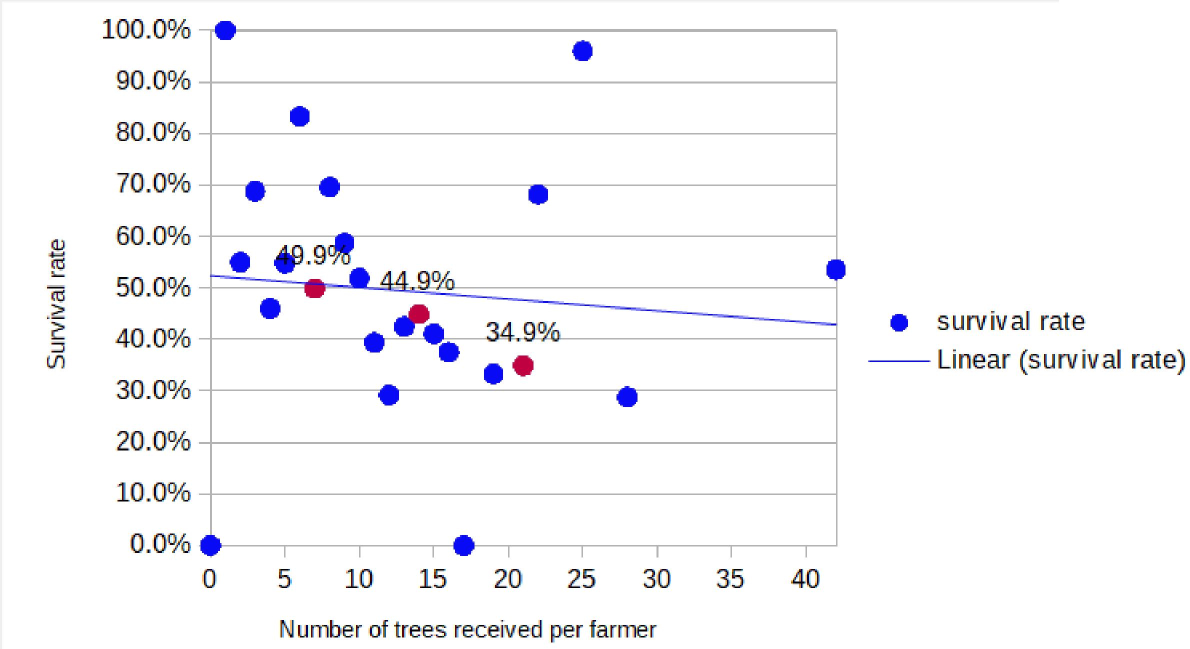


Figure 26: Tree survival rate in function of the quantity of seedlings received by the farmer with linear regression line

Note: The red data point are the point with higher frequency as per the previous chart: 7, 14 and 21 seedlings

A further topic is if a special niche has been used more often for different species using correspondence analysis. In Table 6, there is the two-way contingency table with balloon-plot showing the frequency of occurrence of a niche type with the different species.

The Pearson´s Chi-squared test shows significance as the p-value is very low, only there is warning message:

```
Pearson's Chi-squared test
X-squared = 5299.4, df = 36, p-value < 2.2e-16
Warning message: Chi-squared approximation may be incorrect
```

Contingency table - Species distribution in the different niches

Niches \ Species	Azadirachta i.	Calliandra c.	Carica p.	Mangifera i.	Melia v.	Moringa o.	Senna s.	
Along_Terraces	126	70	31	2208	359	216	115	3125
Ex_Boundary	149	55	78	165	601	73	114	1235
Home_Compond	1351	39	176	1354	955	288	921	5084
In_Boundary	558	56	5	402	939	252	554	2766
Other	36			15	28			79
Scattered	632		44	3046	858	225	121	4926
Woodlot	98	1	1	51	104	18	29	302
	2950	221	335	7241	3844	1072	1854	17517

Table 6: Contingency table/ Balloon-plot Species versus Niches – 2018 – all trees

The two main components are represented in a biplot (Figure 27). The variance represented by this biplot is 74,2 + 15,4 = 89,6% which is enough to make conclusions. The percentage of variance of the remaining dimensions are 5,6% or lower.

	eigenvalue	percentage of variance
dim 1	2.245206e-01	74.21506472
dim 2	4.649578e-02	15.36913120
dim 3	1.674539e-02	5.53517254
dim 4	1.359506e-02	4.49383266
dim 5	1.122757e-03	0.37112610
dim 6	4.741436e-05	0.01567277

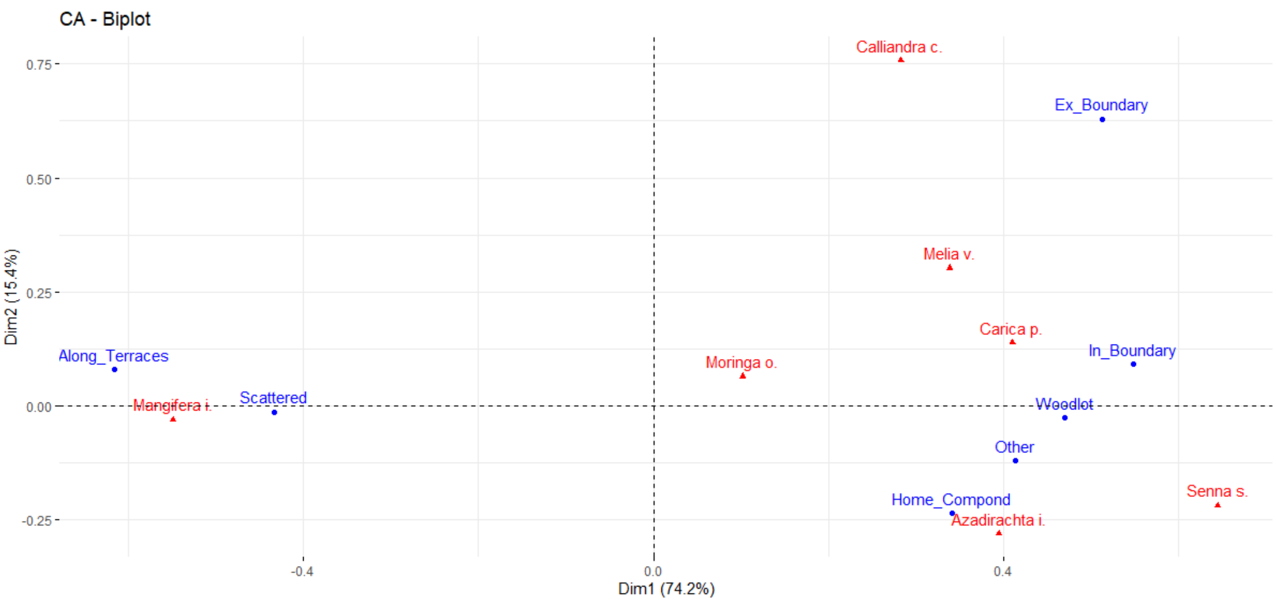


Figure 27: Biplot Correspondence Analysis Species versus Niches – 2018 – all trees

As the dimension 1 covers 74,2% of the variance meanwhile dimension 2 covers 15,4%, dimension 1 is containing more information than dimension 2 and to be preferred to draw conclusions.

Mangifera indica had an affinity with 'scattered in crop land' & 'along terraces' meanwhile *Azadirachta indica* was more often located in the home compound. *Carica papaya* was generally located at the internal boundaries or in woodlots.

For comparison the same data is gathered only for the trees that survived. The Pearson´s Chi-squared test shows similar results of significance through low p-value but with the warning message again:

```
Pearson's Chi-squared test
X-squared = 2218, df = 36, p-value < 2.2e-16
Warning message: Chi-squared approximation may be incorrect
```

Contingency table is Table 7 and the biplot Figure 28.

Contingency table - Species distribution in the different niches - only trees that survived

Niches \ Species	Azadirachta i.	Calliandra c.	Carica p.	Mangifera i.	Melia v.	Moringa o.	Senna s.	
Along_Terraces	50	52	16	1055	161	124	49	1507
Ex_Boundary	49	39	42	57	205	49	44	485
Home_Compond	399	26	77	620	364	146	369	2001
In_Boundary	212	38	3	205	452	143	302	1355
Other	12			5	18			35
Scattered	197		21	1177	317	104	66	1882
Woodlot	39	1		22	32	13	12	119
	958	156	159	3141	1549	579	842	7384

Table 7: Contingency table/ Balloon-plot Species versus Niches – 2018 - trees that survived

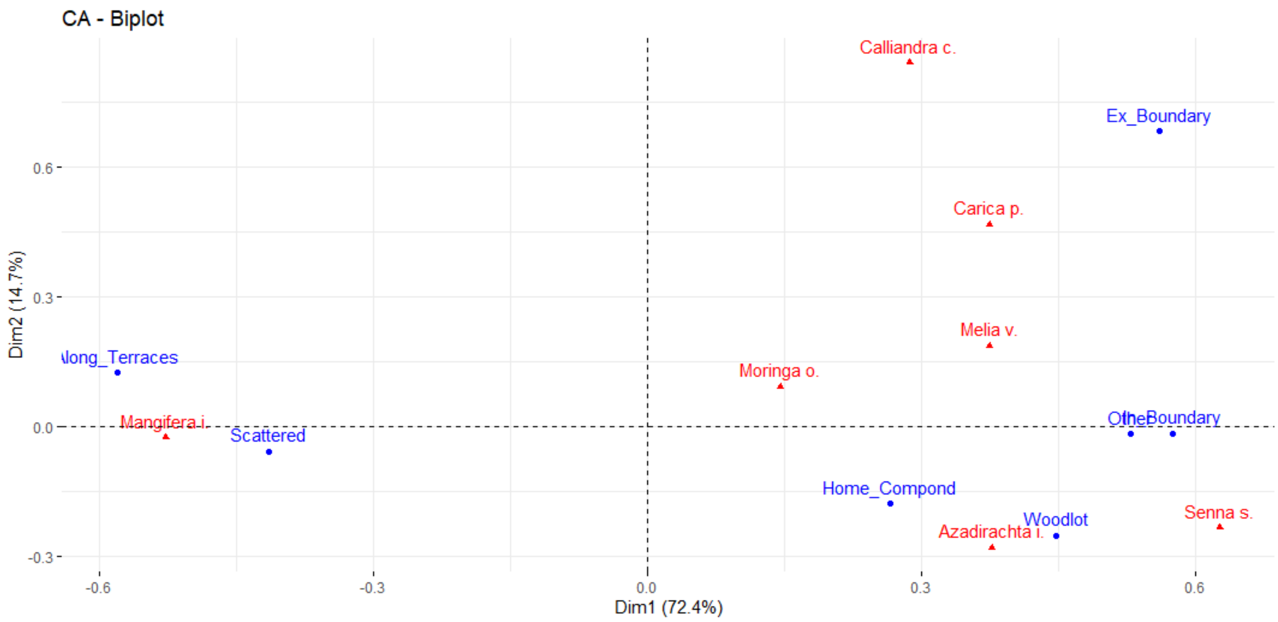


Figure 28: Biplot Correspondence Analysis Species versus Niches – 2018 - trees that survived

Comparing the biplots for all trees and for those which survived could lead to following assumptions: *Azadirachta indica* profited of the woodlot location while *Mangifera indica* seemed to be stable on 'scattered in crop land' & 'along terraces'.

The contingency tables and biplots for 2017 are in the appendix 4: the changes in the biplot between all trees and those who survived lead to the conclusion that *Carica papaya* and *Mangifera indica* were located on 'scattered in crop land' & 'along terraces' and the survival rate was not influenced by the location. Similarly *Azadirachta indica* and *Senna siamea* were predominantly located in the home compound and the survival rates were not influenced by the location.

Tree management practices

This first paragraph is about the influence of the planting hole size on the survival of the trees:

In the 2017 interview, the farmer could choose between following planting hole categories: 2X, 3X or others (Figure 29). 2X refers that the planting hole diameter that is two times larger than the container diameter/ root ball and 3X three times larger.

In 2018 the differentiation was between small holes, big holes and others (Figure 30).

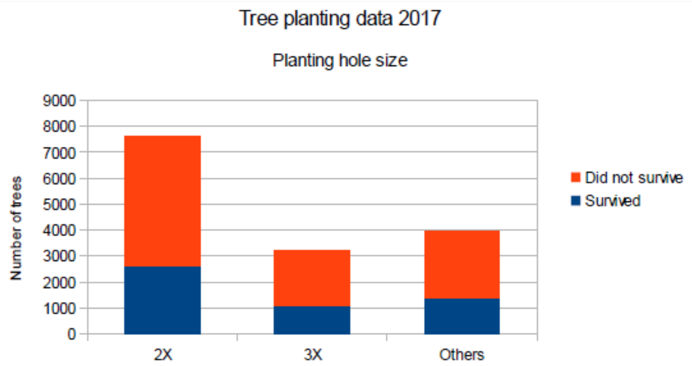


Figure 29: Planting hole size & survival - 2017 survey

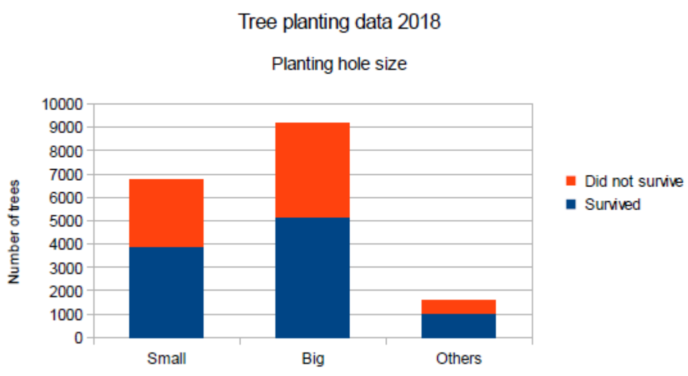


Figure 30: Planting hole size & survival - 2018 survey

In 2017 the majority of the holes were 2X meanwhile in 2018 it was a majority of big holes.

From the 2017 survey, the planting hole size did not affect the survival of the trees, as for each planting hole type there was a similar survival rate (2X:34,2%; 3X:34,2%; Other:35,1%). In 2018 bigger holes have a slightly higher rate than the small holes (43,5% versus 42,3%).

For the category 'Other' the respondent mentioned the diameter of the planting hole. And the next two graphs are showing the distribution that have been achieved in 'Tree planting data 2017' (Figure 31) and in 'Tree planting data 2018' (Figure 32). Very surprisingly the data has a very similar distribution, especially in the 'Tree planting data 2017', so that planting hole diameter was not affecting the survival of the trees substantially. How the planting hole was maintained for instance with manure, mulch or water is also important and this is enhanced in the next section.

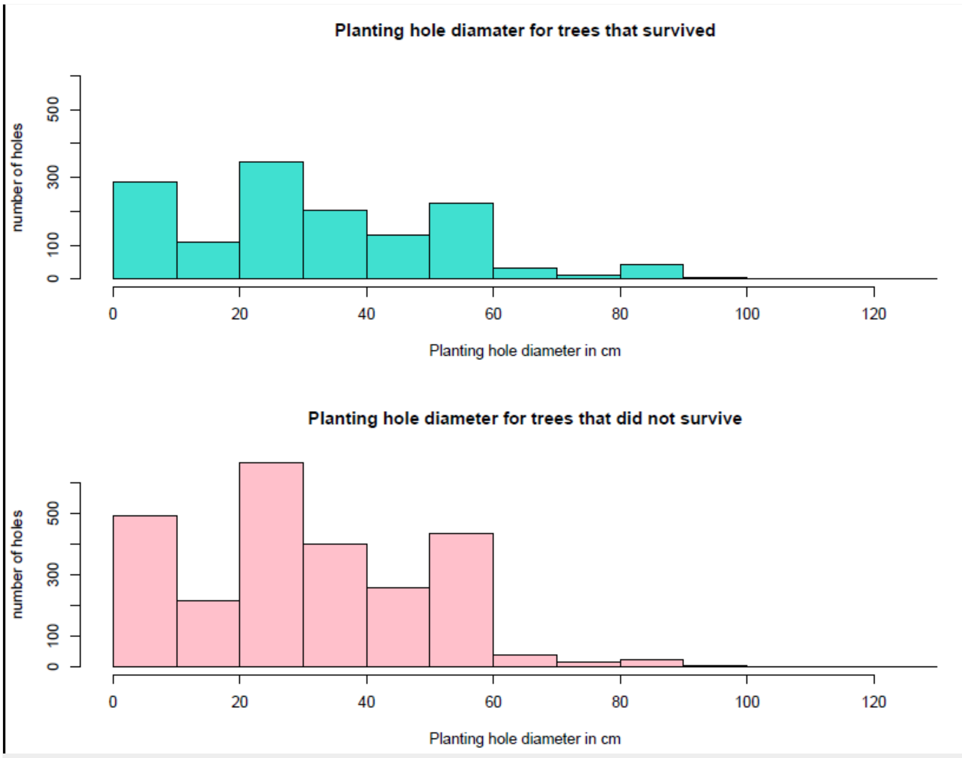


Figure 31: Histogram of the planting hole sizes – 2017 survey

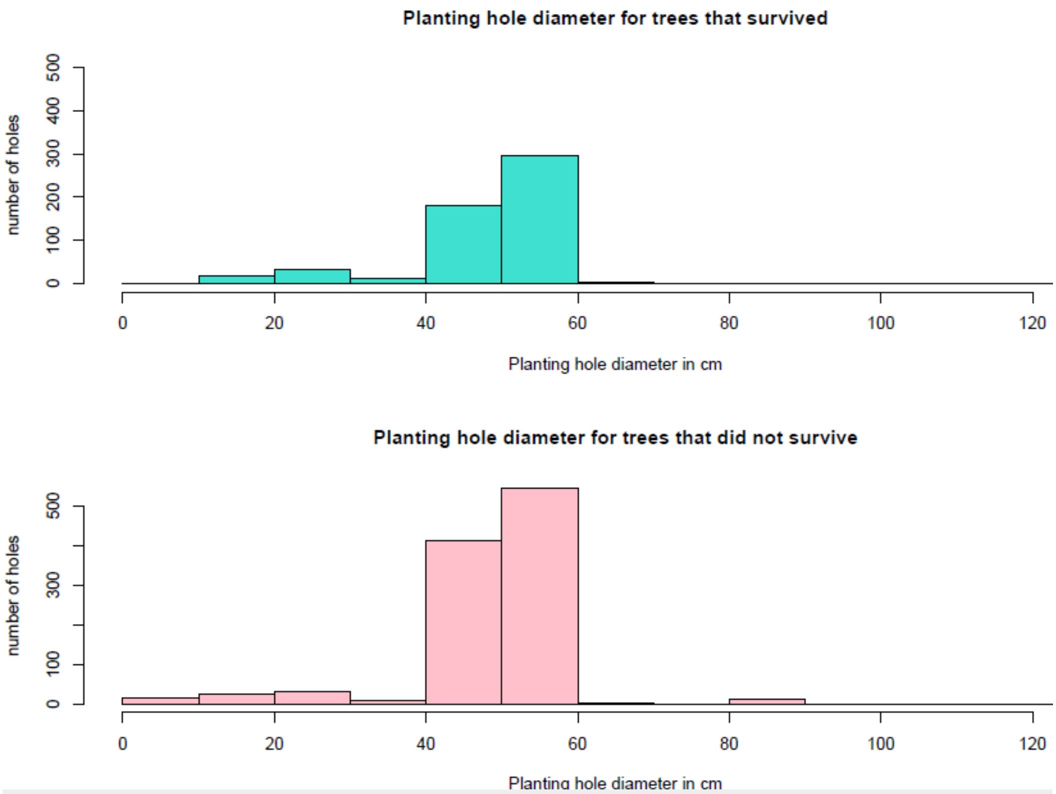


Figure 32: Histogram of the planting hole sizes – 2018 survey

The influence of manure application and mulching is display in Figure 33 and Table 8.

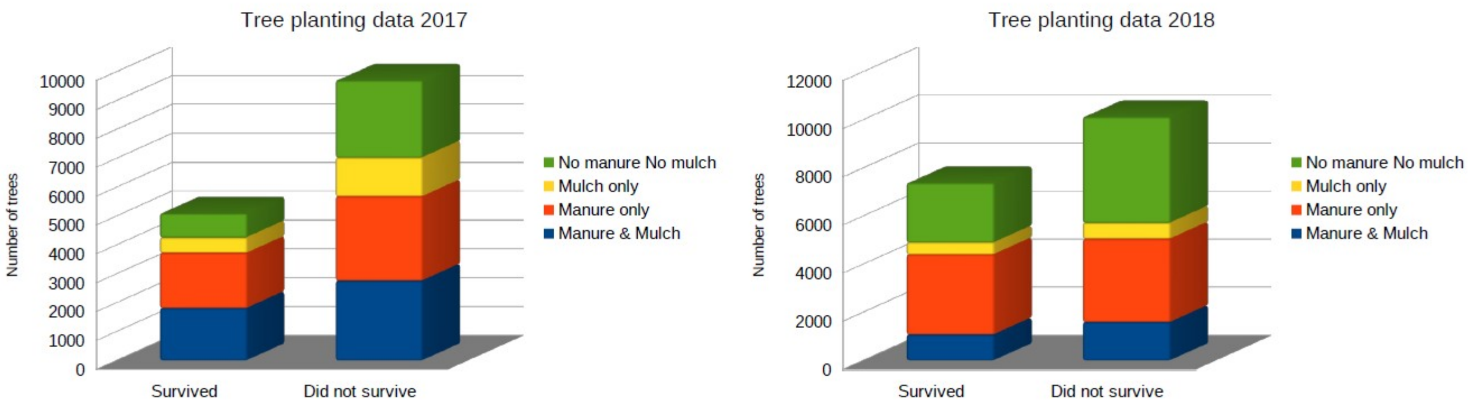


Figure 33: Tree survival depending on manure and mulch application 2017 & 2018

	2017		2018	
	Quantity of trees	Survival rate	Quantity of trees	Survival rate
Manure & Mulch	4582	39.6%	2671	40.3%
Manure only	4834	39.6%	6807	49.0%
Mulch only	1876	28.4%	1146	42.5%
No manure No mulch	3512	23.8%	6893	36.0%

Table 8: Trees quantities and survival rate depending on manure and mulch application

In 2017, the survival rate of trees with manure & mulch and with manure only was the same: 39,6%, with mulch only it felt to 28,4% and without any manure nor mulch to 23,8%.

In 2018, the survival rate of trees with manure & mulch was 40,3%, with manure only 49,0%, with mulch only 42,5% and without any manure nor mulch 36,8%. From this information it was disadvantageous to combine manure and mulch.

Now some more information about general use of manure and mulch from the interview of 'Tree planting data 2018':

54,1% of the trees got manure and the number of manure application since the planting (for those who applied manure) are as per Table 9:

Number of manure applications	0	1	2	3	4	5	8	108
Number of trees	19	8653	773	25	2	3	2	1

Table 9: Number of manure applications per tree

So, farmers in the eight months since the planting of the trees, did one (91,3% of the farmers) or two (8,2%) manure applications.

The quantity applied has been represented in the following histogram (Figure 34):

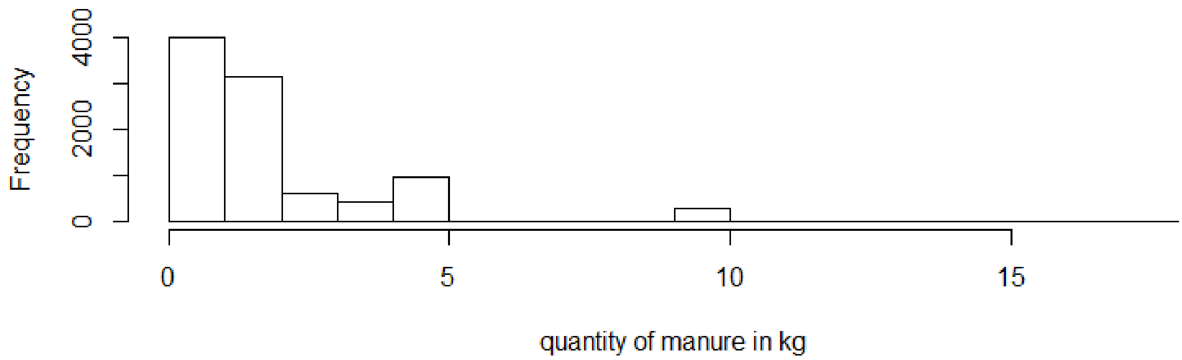


Figure 34: Histogram quantity of manure applied per tree

So the most frequent quantity was 1 kg or less, and almost all farmers used less than 5 kg per tree.

The more frequent methods to measure the application amount of manure were using a spade (40,9%) followed by parroting (kasuku in Swahili) (33,9%) & using handfuls (13,7%).

Then the same data has been gathered for mulch, 21,8% of the trees got mulch. Farmers who applied mulch have been asked how many applications they did since the planting (Table 10).

Number of manure applications	0	1	2	3	4	5	8
Number of trees	8	3451	232	61	20	44	1

Table 10: Number of mulch applications per tree

90,4 % of the farmers applied the mulch once since the planting and 6,1% twice.

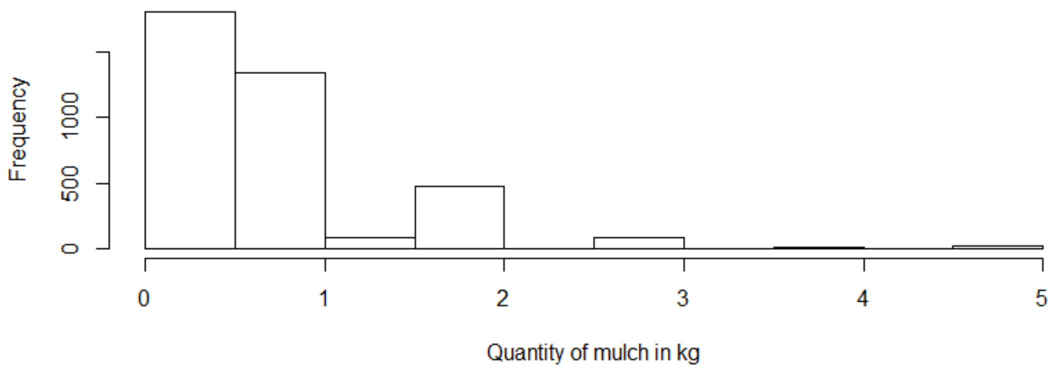


Figure 35: Histogram quantity of mulch applied per tree

On this histogram(Figure 35), 2×725 kg and 1×10 kg has not been represented to not distort the representation.

The most frequent quantity of mulch applied was 1 kg or less.

The more frequent methods to measure the application amount of manure were using handfuls (80,4%) followed by parroting (kasuku in Swahili) (10,9%).

Only 0,4% of the trees received inorganic fertilizer (66 trees out of 17517) and it was applied only once, only one tree got 5 fertilizer applications. The quantity applied varied from 5 g to 5 kg, the median value being 100 g. 36,4% of the measurement was done by handfuls, 31,8% parroting and 27,3% doing pinches.

Concerning watering, in the 'Tree planting data 2017', it was not recorded as in over 97% of the cases the mention was not applicable ('NA').

In 'Tree planting data 2018', 87,1% of the trees were watered during the six months after the planting and the survival rate of the trees, who where watered, increased to a value of 46,2% (the survival rate for all trees was 42,1%). In another way: 95,5% of the trees that survived were watered, but 80,9% of those who did not survive also were watered.

In Table 11 the influence of watering on the survival rate of the different species is presented.

Tree species	Percentage of watered trees [%]	Survival rate all trees [%]	Survival rate with watering [%]	Survival rate increase [%]
Azadirachta indica	82,6	32,5	36,4	12,0
Calliandra calothyrsus	74,7	70,6	75,2	6,5
Carica papaya	91,6	47,5	50,8	7,1
Mangifera indica	88,8	43,5	47,5	9,5
Melia volkensii	83,8	40,3	44,5	10,4
Moringa oleifera	82,4	54,0	63,8	18,0
Senna siamea	97,5	45,4	46,2	1,8

Table 11: Influence of watering on the survival rate by tree species

Moringa oleifera profits the most of watering, followed by *Azadirachta indica* and *Melia volkensii. Senna siamea* is the less sensitive to watering, although this is the tree species where the higher number of trees got watered.

The farmers, who did not water the trees, gave following reasons: seedlings were already dried up, seedlings got destroyed (by livestock), no need as rainy season brings enough rain, the place was moist or near a water course/tank, lack of water, water is expensive, no manpower, tree was already strong, farmer did not know that she/he had to water. The watering frequency occurrence and corresponding survival rate is as per Table 12. Daily watering had the highest survival rate.

Watering frequency	Daily	Every other day	Weekly	Every two weeks	Monthly	Others
Occurrence	10,6%	21,2%	44,6%	16,2%	1,8%	5,6%
Survival rate	57,6%	44,3%	46,1%	44,4%	43.1%	-

Table 12: Watering frequency occurrence and survival rate - 2018

The median quantity of water was 3 litres per tree.

Pruning in 'Tree planting data 2017', has been done on 61 trees, which all survived. The working time for pruning has been always one hour, except one tree where it took 2 hours and another tree where 5 hours have been mentioned.

About the fencing, in 'Tree planting data 2018': 30,4% of the trees were fenced. The fencing increased the survival rate from 42,1% to 46,9%, slightly more than the watering seen earlier.

Similarly, Table 13 is showing the influence of fencing on the survival rate for the different tree species.

Tree species	Percentage of trees with fence [%]	Survival rate total [%]	Survival rate with fencing [%]	Survival rate increase [%]
Azadirachta indica	30,5	32,5	39,4	21,3
Calliandra calothyrsus	22,6	70,6	80,0	13,3
Carica papaya	82,4	47,5	52,2	9,9
Mangifera indica	29,8	43,5	49,5	14,0
Melia volkensii	29	40,3	42,2	4,8
Moringa oleifera	15,6	54,0	68,9	27,5
Senna siamea	35,7	45,4	46,7	2,8

Table 13: Influence of fencing on the survival rate by tree species

Farmers were fencing more often *Carica papaya* (82,4%) and fencing is especially advantageous for *Moringa oleifera* (increase of the survival rate of 27,5%) and *Azadirachta indica* (increase of 21,3%).

Concerning shade, 7,2% of the trees were protected from the sunlight and it increased the survival rate to a value of 49,2%.

Tree species	Percentage of trees with shade [%]	Survival rate total [%]	Survival rate with shade [%]	Survival rate increase [%]
Azadirachta indica	2,8	32,5	31,7	-2,4
Calliandra calothyrsus	19,5	70,6	76,7	8,7
Carica papaya	25,1	47,5	60,7	27,9
Mangifera indica	8,5	43,5	54,9	26,5
Melia volkensii	8,7	40,3	37,9	-5,9
Moringa oleifera	3,8	54,0	53,7	-0,7
Senna siamea	3,2	45,4	40,7	-10,4

Table 14: Influence of shade on the survival rate by tree species

The farmers are providing shade principally to *Carica Papaya* (25,1%) and to *Calliandra calothyrsus* (19,5%), nevertheless the tree species which profited most of the shade were *Carica Papaya* (increase of the survival rate of 27,9%) and *Mangifera indica* (increase in the survival rate of 26,5%) as per Table 14.

Reasons of non-survival

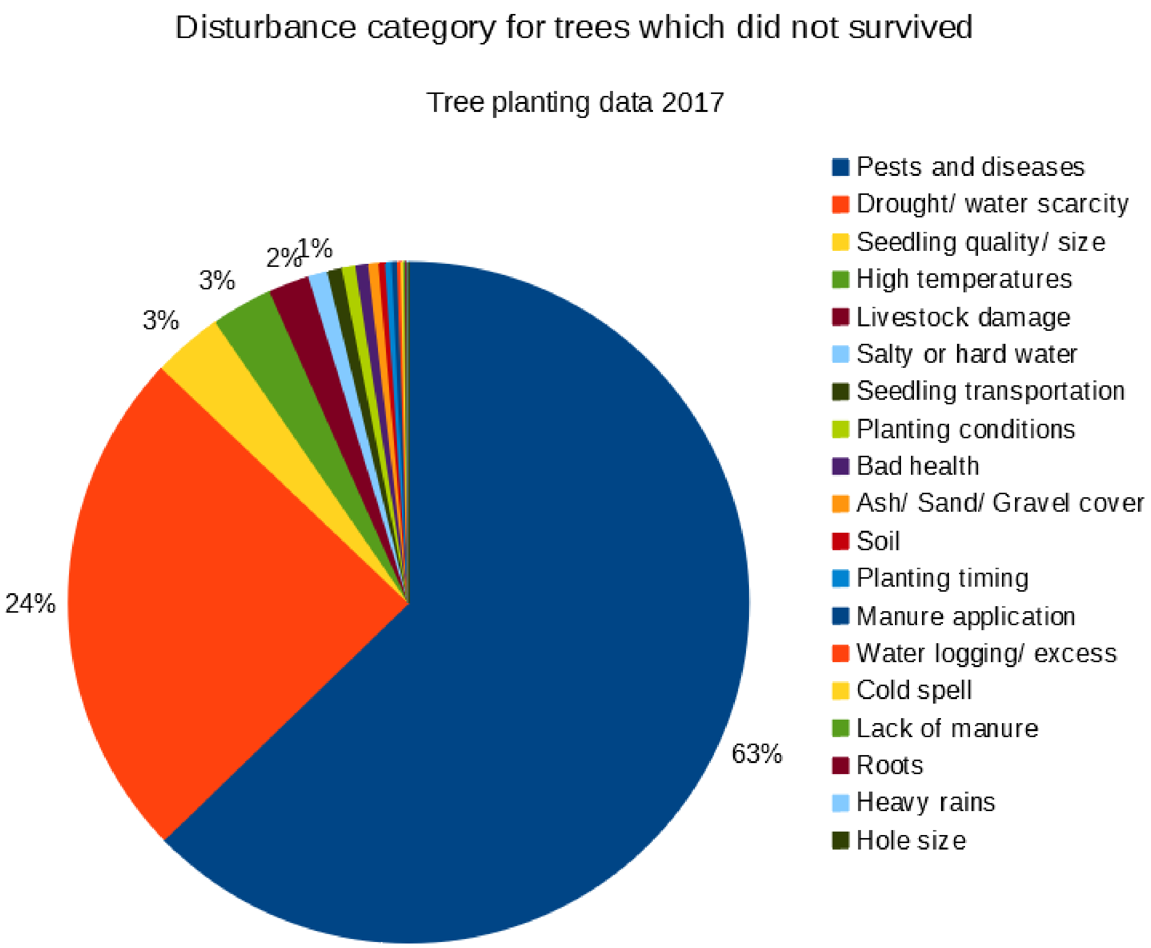


Figure 36: Disturbance category 'Tree planting data 2017'

In 'Tree planting data 2017' the notes allowed the farmers to give a final comment. From the 9704 trees which did not survive, 4526 trees got a comment. Those comments have been summarized in disturbance categories that could be the reason of the tree death (Figure 36). In case there were different responses for possible disturbances, only the first one has been considered. 'Pests and diseases', contains the ants, termites and worms and was the main disturbance with an occurrence of 63%. Drought/Water scarcity (27%) which is also highly connected to high temperatures (3%) was the second occurrence. The seedling quality/size and a bad seedling transportation is also mentioned as the third reason of non-survival.

From those notes some farmer insights can be summarized as follow:

- manure application could be the reason of the tree to die, mentioned for 12 trees.
- Ash can be used to kill termites but may damage the tree, charcoal is also used against termites
- Mulch attracts termites and need to be changed often, as soon as mulch is dry
- Mixing of sand soil with subsoil before planting the tree protects it from ants

In 'Tree planting data 2018', the farmer were requested to respond 'yes' or 'no' to some possible reasons of non-survival of the tree: drought (43,6%), pests (35,2%), livestock damage (26,3%), poor seedling quality (20,7%), diseases (19,9%), too much water (7,2%) and other (3,6%). As a farmers could give more than one answer the total is above 100%.

The main remarks from the variable 'other' are:

Lack of water/ water stress/ inappropriate water application - 159 times;

Human damage (e.g. children or while ploughing) - 42 times;

Poor soil / rock soil / sandy soil/ hard pan/ compact soil - 29 times;

Destroyed by rains/ flooding - 27 times;

Planting hole too small - 13 times;

Water quality - 12 times;

Different soil reactions effect - 10 times;

Seedling transportation - 9 times.

Tree species and ecosystem services

This sub-chapter is aiming at providing an understanding of the seven tree species of the project and at investigating how they contributed to improve livelihood and maintain ecosystem services.

First, the definition of ecosystems and ecosystem services will be remembered, and a basic list will be proposed with the ecosystem services of trees on farm as introduction to the topic.

Then, the tree species will be described in short, a more detailed description of each tree species of the project with some photos have prepared and is located in the appendix 5. Then, a table will summarize this information for better comparison between tree species.

Afterwards, a focus is given on farmer's choice for tree species, with an emphasis on gender and the trees, that farmers planted/are planning to plant outside of the project.

Finally, a special paragraph is dedicated to the farmers, who took part to the project on two consecutive years.

Ecosystems services of trees on farms

As per the Millennium ecosystem assessment (2005), ecosystem services have been defined and distinguished into four categories, these are shown in the Figure 37.

First, the report gives a definition for ecosystems:

"An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit. Humans are an integral part of ecosystems."

and for ecosystem services:

"Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits."

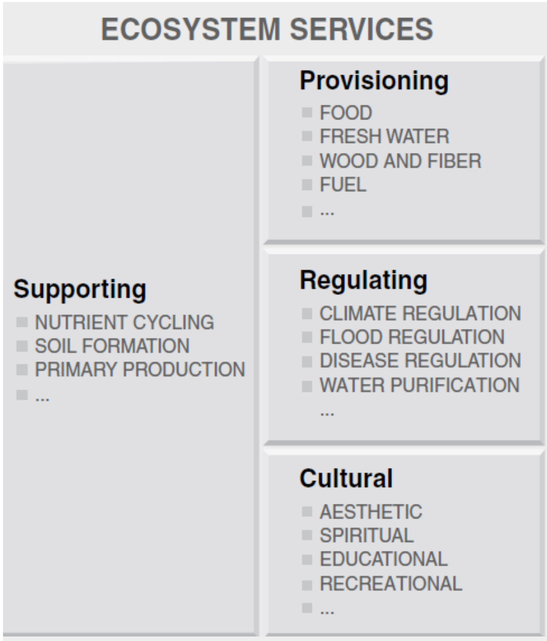


Figure 37: Ecosystem services
Millennium ecosystem assessment

The supporting ecosystem services are represented ahead due to their supporting function of the other three ecosystems services.

Trees on farm can provide following ecosystems services:

- supporting: soil organic matter in form of litter, water retention in the soil, nutrient retrieval from deeper soil levels, atmospheric nitrogen fixing, habitats for micro and macro-fauna, oxygen production; pollination
- provisioning: fuel-wood, timber/building material, fruits, medicine, teas from leaves or flowers, gums, dye, fodder, mulch;
- regulating: water infiltration instead of run-off, pests and diseases (can be also de-regulating), leaching reduction and therefore preserving

nutrients, soil erosion reduction, carbon sequestration;

- cultural: aesthetic e.g. ornamental plants, living/resting areas, shade, humid/ cooler places, appealing landscape.

Tree species of the project

The six species, which have been part of the project in 2016, are: *Azadirachta indica* (neem tree), resistant to dry climate and also famous for the medical applications of its fruits; *Carica papaya*, well-known for its fruits (papaya) and that grows in warm climate and sunny sites; *Mangifera indica*, also well-known for its fruits (mango) but produces also timber and firewood; *Melia volkensi* (Mukau in Swahili), the only indigenous tree from the project, providing excellent timber; *Moringa oleifera*, which provides oil from its seeds but can also be used as wind-breaker; *Senna siamea* (cassia) suitable in lowland tropics with monsoon climate and that provides high energetic fuel wood and great quantities of green manure. In 2017, *Calliandra calothyrsus* was also part of the project, a leguminous shrub which grows on infertile soils and help against soil erosion and undesired weeds, and is appreciated for the bitter-sweet honey from the nectar of its flowers.

Those seven tree species are presented in more details in the appendix 5. The description in based on the ICRAF tree database, Orwa et al (2009). Additionally to some common names, family and origin of the tree species, this description gives information on the botanical traits of the trees, the conditions needed for their growth and the products and services they provide. Some photos from other sources have been added showing whole trees, leaves, flowers, fruits and trunk.

Table 15 shows the principal information about the trees:

	Azadirachta indica	***Calliandra calothyrsus***	***Carica papaya***	***Mangifera indica***	***Melia volkensii***	***Moringa oleifera***	***Senna siamea***
Continent of origin	Asia	America	America	Asia	Africa	Asia	Asia
Economical profitability	10-200 years	After 2 years	Half-year to 5 years	Up to 10-20 years	After 2-3 years		After 2-3 years
Location/ Climate	Lowland tropics	Humid and sub-humid zones[7]	Warm climate	Subtropics and tropics[8]	Drylands	Near rivers or high-water table	Monsoon climate
Altitude (m)	0-1500	Up to 1300	0-1600	0-1200 (tropics)	350-1680	0-1000	<1300
Sensitive to	Water logging, frost		Wind, Water logging, frost, floods				Cold, frost
Need	light		sun				light
Resistant to		Infertile areas		Drought and flood		Drought and frost	
Mean annual Rainfall	400-1200 mm	700-4000 mm	1000-2000 mm	300-2500 mm	300-800 mm	>500 mm	400-2800 mm
Temperatures	Up to 40°C	22-28°C (mean annual)		24-27°C (optimum)		13 to 40°C	20-31°C
Erosion control	+	+				+	+
Shade	+	+		+			
Soil improvement	+	+ (N Fixing)		+	+	+	+
Medicine	++		+	+		++	+
Food	+		++	++		+	+
Timber	+			+	++	+	+
Fuelwood	+	+		+	+	+	+
Fodder	+	+		+	+		
Ornamental		+					+
Others	Seed oils, pesticides	Apiculture, fibre Dominate undesired weeds	Latex/ rubber	Tannin, apiculture	Apiculture, poison	Tannin, fibre	Tannin

Table 15: Tree species matrix

7 There are seven agro-climatic zones (ACZ) in Kenya which are based on the vegetation patterns, the rainfall characteristics and the ecological potential. They are as follow: I – humid, II – sub-humid, III – semi-humid, IV – semi-humid to semi-arid, V – semi-arid, VI – arid and VII – very arid (Chepkoech et al, 2020).

8 Tropics are located between the tropic of Cancer and tropic of Capricorn around the Equator meanwhile subtropics are located north of the tropic of Cancer and south of the tropic of Capricorn towards the temperate zones.

Decisions on tree planting & species

The decision to plant trees was done by the farmer her/himself. About the tree species, in 6% of the cases, the farmer mentioned that other actors were involved in choosing the tree species: the project (21 responses), the donor (3 responses), drydev (31 responses), organization/group (22 responses), ICRAF (8 responses). They all stand for the organisation, that gave the farmers the tree seedlings.

The location was entirely decided by the farmer family. As per the decision to plant trees and which species, husbands were more involved than wives.

Male and female household heads had similar species distribution (Figure 38)

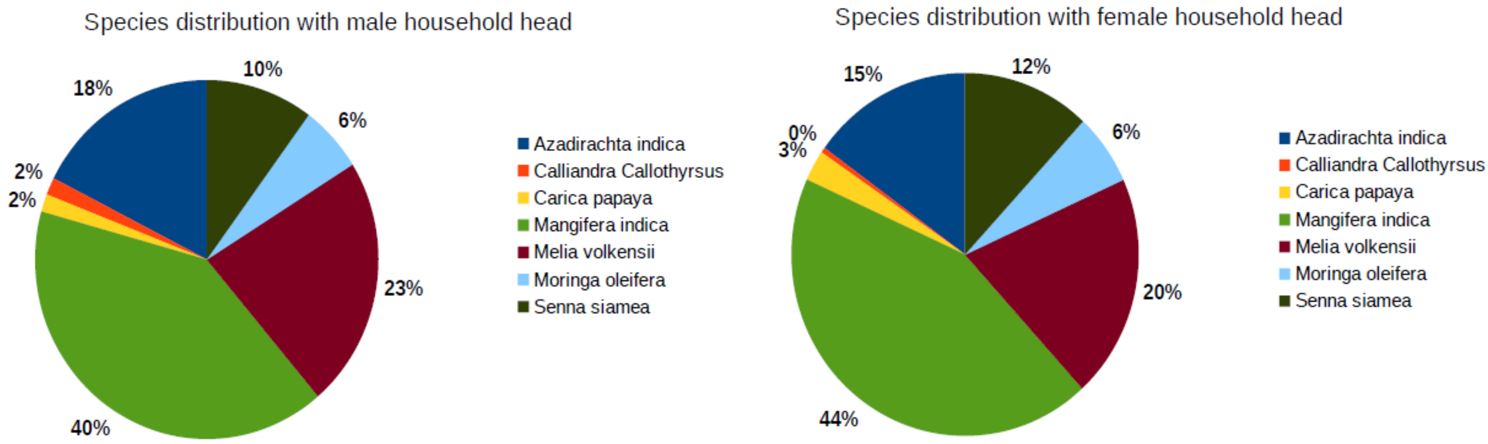


Figure 38: Species distribution depending on male and female household heads

26,3% of the households (372 households) purchased additional tree seedlings during the twelve months prior to the survey. The quantity of trees and the species were recorded.

From those 372 households, 13 households bought more than 50 trees and the tree quantities are: 55; 60 (4 households); 84; 100; 130; 150 (3 households); 300; 500. The majority of the households (117) bought 5 trees or less.

The following histogram (Figure 39) shows the distribution of quantity of trees bought by the households up to 50 trees:

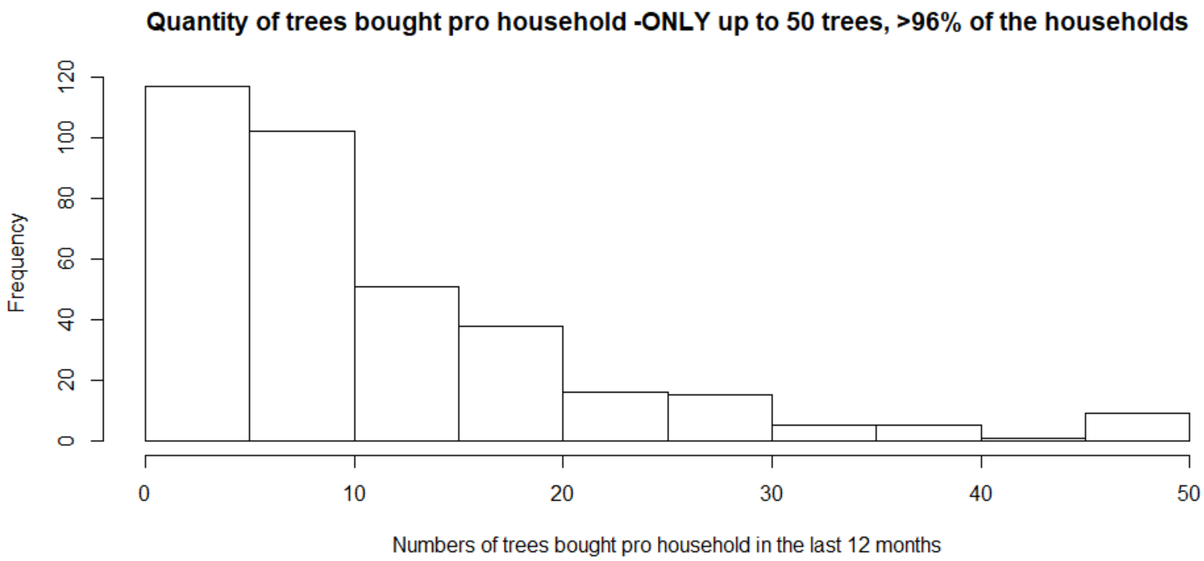


Figure 39: Quantity of trees per household purchased in the previous 12 months

The species bought are listed as follow, many families mentioning several species. The number behind the tree species is the number of times, the tree species has been mentioned by a household.

Mangifera indica (mango, miembe) 207
Carica papaya 83
Azardirachta indica (neem, mwarobaini) 39
Senna singueana (mikengeta) 39
Melia volkensii (mukau) 28
Elaeocarpus bifidus (kalia) 18
Mchora 18
Moringa oleifera 15
Mualuvaini 15
Senna siamea 10
Umbrella 10
Avocado 8
Muvaliti 7
Gruveria/ Grevillea/ Grivelia/ Gruvillea 6
Guava 6
Orange 5
Passion fruits 5
Croton 4
Flower plants/trees 4
Kitomoko 4
Lemon 4
Mikau 4
Tomoko 4
Misanduku 3
Mitomoko 3
Tulila 3
Zambarau 3
Acacia 2
Banana 2
Citrus 2
Itimo 2
Jacaranda 2
Karia 2
Karira 2
Kithuri/Kithuru 2
Mkonde 2
Monica 2
Mubariti 2
Been 1
Bluegum 1
Calliandra calothyrsus 1
Cypress 1

Eucalyptus 1
Guanabana 1
Ikengeta 1
Indigenous trees\n 1
Inina 1
Isungwa 1
Ithuru 1
Iukena 1
Kalila 1
Kayapple 1
Kayava 1
Kikundi 1
Kitae 1
Kithulu\n 1
Leucaena 1
Miti Mumo 1
Mkonde 1
Miambrella 1
Mitimu 1
Mlangord 1
Msoda 1
Muaba 1
Mukekengeets 1
Mulului 1
Muti wa mbui 1
Muchristmas 1
Musanduku 1
Muthulu 1
Muti wa mbui 1
Muuku 1
Sesbania 1
Strawberry 1
Venesi 1

The seven species from the survey have been highlighted and with exception of *Calliandra calothyrsus*, tree species of the project were at the top of the farmers' choices.

From the 1416 surveyed households, 1082 households mentioned that they are planning to plant additional tree seedlings in the following 12 months, from which 1027 households mentioned a number of intended tree seedling planting of 50 or less, this consisted of almost 95% of the households (Figure 40).

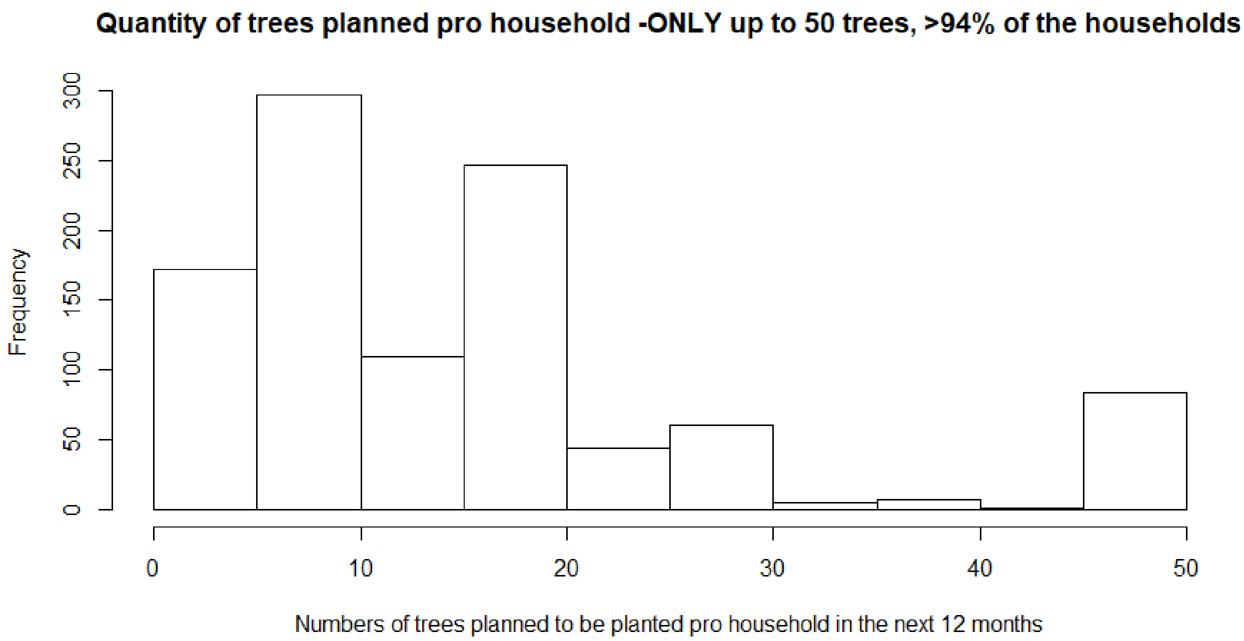


Figure 40: Number of trees per household planned to be planted in the following 12 months

Then, the farmers could specify the tree species that she or he would plant. The following list shows the trees species mentioned by the farmers and how many times it has been mentioned.

Mangifera indica (mango, miembe) 706
Melia volkensii (mukau) 254
Carica papaya 225
Senna singueana (mikengeta) 168
Azadirachta indica (neem, mwarobaini) 138
Moringa oleifera 138
Orange 59
Mualuvaini 35
Muvaliti 22
Senna siamea 21
Grevillea/ Gruveria/ Grufelia/ Gruveria 17
Mchora 16
Avocado 12
Isunga/Isungwa 10
Calliandra calothyrsus 8
Musanduku/ Misanduku 8
Acacia 7
Citrus 7
Mchora 7
Passion fruit 7
Umbrella 7
Kalia 5
Tomoko 5
Croton 4
Guava 4
Iembe 4
Kitomoko 4
Lemon 4
Mitomoko 4
Eucalyptus 3
Banana 2
Beauty/flower plants 2
Been 2
Ivakato 2
Jacaranda 2
Kamulia 2

Leucaena/ Leukena 2
Miraa 2
Mithulu/ Muthulu 2
Mitimu 2
Muuku 2
Mubariti 2
Ndimu 2
Benjamina 1
Ithulu 1
Itimo 1
Iukenga 1
Kalimilia 1
Kayapple 1
Kithulu 1
Kukumanga 1
Lucerne 1
Mkonde 1
Monica 1
Musau 1
Muthiia 1
Muthulu 1
Rubber tree 1
Tulia 1
Tulila 1
Woody trees 1

Highlighted in violet are the trees from the survey. There was a match in the sense that the trees proposed by the organization, were also those the farmers were planning to plant in future.

From the 1082 farmers, which planned to plant trees within the following 12 months, 738 (68,2%) had to buy seedlings, 476 (44,0%) had some of them free of charge, 280 (25,9%) got them from their own nursery, 12 (1,1%) mentioned other sources such as from natural offspring, seeds (from bush, nature reserve or market), neighbour.

1013 farmers told that they planned to use their own planting method (93,6%) against 69, who did not. 389 farmers planned to dig small planting holes (36,0%) and 693 not. 737 farmers planned to dig big planting holes (68,1%) and 345 not. 892 farmers planned to use manure and mulch (82,4%) and 190 not. Only 26 farmers planned to use inorganic fertilizers (2,4%) and 1056 not. 917 farmers planned to water the seedlings (84,8%) while 165 not. 587 planned to fence the seedlings (54,5%) while 495 not and 209 farmers planned to shade the seedlings (19,3%) while 873 not.

In the comments, farmers mentioned that a rocky soil make it difficult for them to dig profound holes. 2x2 feet hole is a common mentioned size. Sand and ash are also sometimes added to the hole or top soil.

The farmers, who responded that they are not planning to plant some more trees in the next twelve months, mentioned following reasons:

- No funds to buy seedlings/ no return on investments;
- No water availability/ nobody to fetch water/ long distance to water point;
- Advanced age of the farmer/ No time: school, sickness, other job;
- Farmer is moving/ land use change;
- Low tree survival rate due to e.g. termites, ants, climate, neighbour livestock, soil;
- Intensive work related to tree keeping/ no interest or capacity to maintain more trees;
- not enough space in the farm.

Households participating on both years

From 'Tree planting data 2018', out of 1416 households, 992 were part of the project in 2016 already (70,1%), it means that in 2018, they were taking part to the project for the second time.

Trees from households, who did not participate the previous year to the tree planting, had a survival rate of 43,1%. Trees of households, which participated to the previous tree planting action, got a survival rate of 42,0%. So, the experience of the first year did not clearly resulted in an increase of the tree survival rate.

From those 992 households, only 139 (13,3%) mentioned to have had trees in production. The households, who were not part of the project in the first year, did not answer the question.

The households mentioned the products provided by those trees, which were firewood, fruits (mangoes, moringa fruits, papaya), leaves (e.g. moringa, neem), seeds (moringa), vegetables.

The farmers were then requested to mention the use of the product. Following uses were mentioned: pesticide, food, medicine (for stomach, malaria treatment, chewing the leaves, boiled or crushed as powder, e.g. moringa leaves), fodder, selling, shade.

The following graph (Figure 41) shows which species have been chosen in 2018 by the first-year farmers and by the second-year farmers:

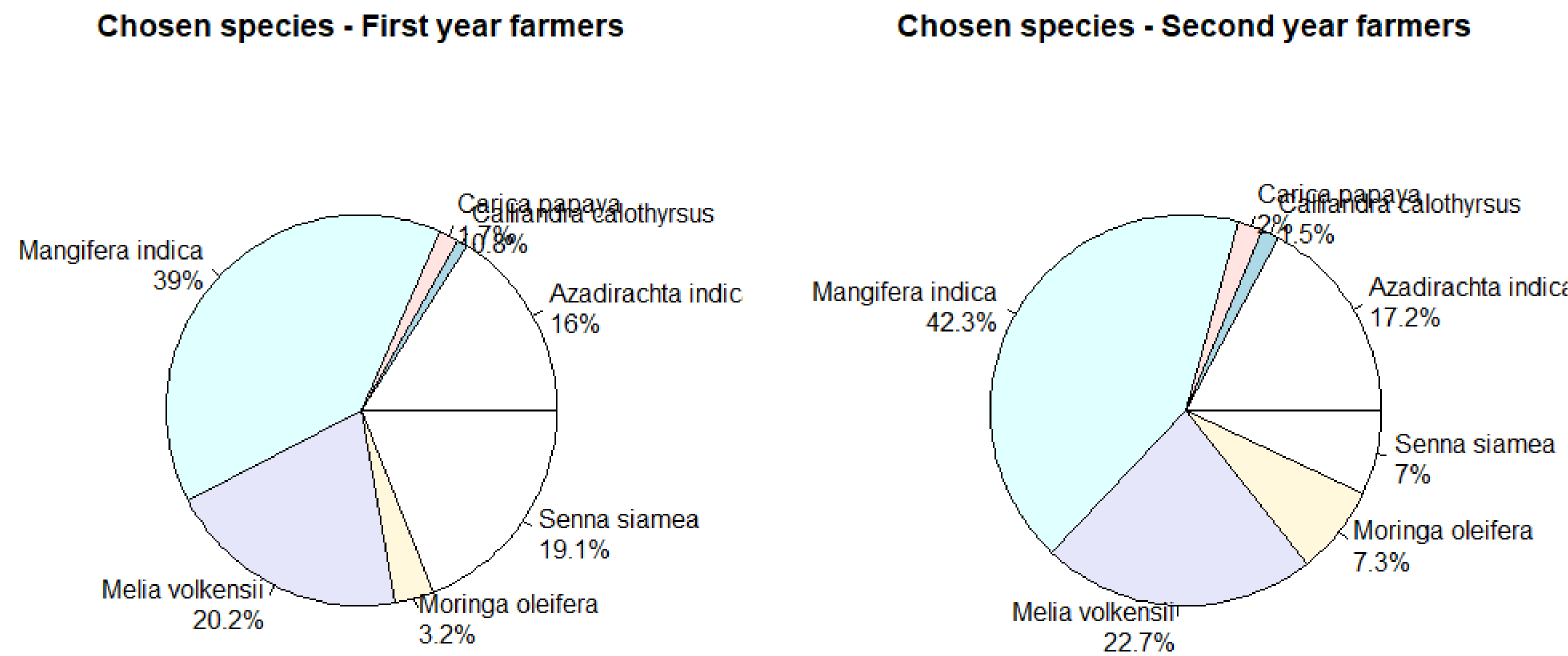


Figure 41: Tree species choices between first and second year farmers - 2018 survey

The second-year farmers had less interest in *Senna siamea* (7% versus 19,1% of first-year farmers) compensated by a higher interest in the other species especially *Moringa oleifera* (7,3% versus 3,2% of first-year farmers).

CHAPTER 4 DISCUSSION

Socio-economic analysis of the farmer interviews

In order to design agricultural development policies, it is important to understand the main actors, the farmers, who do not form a homogenous group; therefore the analysis of households and their dynamic is crucial, especially taking into account farmer gender and age (FAO, 2014).

Age, gender and responsibilities within the farm

The median age of the household head with 49 years is definitively high especially knowing that according to Kenya Aid, an NGO, the median age in the country is 18 years and the average life expectancy of 59 years[9]. This is to be justified by traditional land tenure systems (Ochieng et al, 2016). More precisely, there is actually a shift of customary land tenure due to neo-liberal reforms that unfortunately have negative consequences for smallholder farmers, reducing their land surface and therefore increasing inequalities (Chimhowu, 2019). Rural youth in Kenya does not see prosperous future in agriculture, especially young women, who have less access to clear land titles and see better opportunities elsewhere; in fact, in Kenya, only 15% of the younger generation is actively involved in agriculture (FAO, 2014). Also, agricultural work does not have high prestige, is physical and is often related to low/negative income and precariousness and therefore not very attractive for younger generations. As a consequence, the sector is less innovative and introduction of new techniques or methodologies may be slowed down. In the article of Crossroad & Paez-Valencia (2020), a woman farmer mentioned that after she applied planting holes (zai pits) for her crops, her children were surprised by the good results and decided to bring her seeds. This testimony shows how younger generation may get re-interested in farming if higher

9 https://kenyaaid.org/about-us/about-kenya/

yields were achievable.

There was a slight trend that older household heads have a lower tree survival rate, also to a lesser extend younger household heads. Tree planting projects, with older farmer involved, need to consider how support can be provided, that would alleviate the farmers of physical activities such as watering, fencing or pruning.

The tree survival rate, although slightly higher in a farm with a female household head (42,6%) is very similar to the rate in a farm with male household head (41,6%). The typical household is based of a man and a woman, and the spouse of the household head is usually also working in the farm. Men and women are interwoven in their household context and both are involved in decision processes. Crossroad & Paez-Valencia (2020) mentions gender dynamics within households, where decisions are taken with a form of consultation between the spouses and where women are more subject to take decision alone when the husband is working elsewhere. Also, women may have difficulties to implement new technologies learnt in a training, if their husbands were not part of the training.

Nevertheless, household heads were predominantly men (71,2%) but interviews were answered more often by women (about 2/3) and tree planting work was mainly done by the female farmer. Additionally, almost 80% of the farmers doing the tree digging and planting, were answering the interviews by themselves, also in the case they were not household head. This is a positive aspect as women can be the contact person toward outside, although they are not the owner.

Women are more at risk to become overloaded with the additional work related to land restoration measures (Crossroad & Paez-Valencia, 2020) as they have other duties caring for the family. Hired personal is nevertheless almost mainly men, probably due to the physical work to be performed. Also, within the families, girls and grandmothers are less active in the tree planting activities.

The household head gets involved where the input is scarce or expensive such as the synthetic fertilizer application.

As more than 70% of the households mentioned that tree planting and tree management increased the time spent working on the farm, trees need to be generate revenues. This result has also been confirmed by the study of Nyberg et al (2020), where higher tree density was connected to a higher workload and less off-farm revenues. As a response the authors mentioned the importance of research and development on sustainable and profitable practices and mentioned the mechanization pathway in order to attract the younger generation.

Some results were not consistent, for instance the household head was almost never involved in tree planting as it scores 0,2%, probably due to the redundancy of the question. As 79,3% of the interviewees did the work by themselves and 38,4% were the household heads, so that it should be at least 30%. In a third database, called 'Farmer Profiling Data - Kenya' (Winowiecki et al, 2019a) there is remark that “the information is not verified and can contrast with other information” about farmer gender and her/his relation to household head. Also, it is written that sometimes the data collector did not include the farmer in the overall count. Those uncertainties make it more difficult to understand the role of each family member.

Food security and migration

Although the household survey showed optimistic farmers and confident regarding food security in the year 2018, more than half of them also mentioned that they had to skip meals or eat less during the past twelve months.

In case of shortage, farmers rely on external sources such as selling assets (28,3%), receive remittances (15,8%) or looking forward to receive aid (12,0%). In the survey of Hughes et al, (2020), 22% of households mentioned to rely of remittances from relatives living elsewhere. The percentage of farmers looking forward to received aid is in fact lower than those who received aid the last 12 months (18,6%). So food aid is reaching (in percentage) the expectation of the farmers.

49,7% of the interviewed farmers were born in their actual village and 49,1% had their parents also born in that village. This means that almost all farmers born in the village has also their parents born there. More than half of the farmers migrated to their village, as a lot of spouse answered the interview (57,3%), this can be one reason. Farmers between 40 and 50 y.o. are born in the seventies. As the country got independent in 1963, land used by the British colonialists became free in that period (Nyberg at al, 2020). So that parents of the farmers could have migrated but this is not reflected here.

Only 0,4% of the farmers would move to another place if they had 25.000 KES, so the pressure to migrate is very low.

Access to land and investment priorities

The most frequent farm size was between 1 and 2,5 hectares, which is within the smallholder farmer category. The best tree survival rate was reached for farms with a surface from 2 to 10 hectares. Land was mainly owned (94,4%) and 95% of them had a title such as a title deed or an allotment letter. This means, that the land tenure is secure, which is favourable to the practice of agroforestry, due to middle or long-term investment that trees represent. The farmers also mentioned that their land can be securely used in future on more of 97% of the cases and most of them have the land near their house. The literature often mentions a precariousness of farmers concerning their tenure rights as it affects the potential to invest in new technologies and get access to loans (Chepkoech et al 2020) mainly in West Africa (Stewart et al, 2020). This was not reflected in those interviews.

According to Mercy Corps[10], a global NGO active in Kenya since 2008, the country is still suffering from the same problems as per the 2007's post-

10 https://www.mercycorps.org/were-we-work/kenya

election crisis which are competition over land, strong poverty, high rate of unemployment, youth crisis and political tension. On one hand, farmers have a secure land they can rely on, but on the other hand, to acquire new land is difficult.

About the investment on farms, farmers were preferring livestock (36,4%) to trees (16,9%). Also in Jerneck & Olsson (2013), farmers prefered an investment where cash could be generated easier e.g. while selling livestock and some farmers mentioned that livestock is needed prior investing in agroforestry. Agroforestry is considered as a costly investment to face climate change, that many farmers in Kenya cannot afford, although they would be willing to do so; Promotion through agricultural development programs could be beneficial (Brian et al, 2013).

35,7% of the farmer would also like to open a business. Farmers are creative and willing to diversify their activities.

This is also confirmed by the list of others investments on farm that farmers would do as well as the land restoration/ land management measures they would like to undertake, which shows that farmers are very aware of options and alternatives. Tree planting measures are almost always combined with other Sustainable Agriculture Land Management (SALM) (Hughes et al, 2020).

Factors of tree seedling survival

Planting date & climate

The climate data in Makindu (Makueni county) and Mutomo (Kitui county) showed an annual bimodal rainfall with the stronger rainfall in November/ December followed by a more moderate rainfall in April. The main dry period is going from June to September.

The trees have been predominantly planted in the last weeks of November in the middle of rainy season so that the soil was already wet and the seedlings got enough rain in the first month after plantation.

Precipitation is recognized as the key factor for drought from which agriculture, livestock and households are dependent in most sub-Saharan African countries, this is especially true as many countries lack the capacity of drought remediation (Okal et al, 2020).

The precipitations in October/ November 2017 were definitely above average, so that the planing for tree planting cannot be done exclusively on such favourable conditions but have to consider drought years.

In the survey, the tree heights and trunk diameters were notably higher in 2018, which confirm the positive climate conditions but this can also be related to the seedling quality. That is in correlation with the higher survival rate as evidently bigger trees are more subject to survive. The survey took place one month later in 2018 (July) than in 2017 (June) which may also slightly affect the tree sizes between the two years.

Kenya has a history of droughts, to cite only the most recent ones:

- 2010-2011 drought affected the whole Horn of Africa including Kenya, Somalia and Southern Ethiopia and leaded to 250.000 deaths in Somalia alone and was a humanitarian catastrophe;
- another drought started in 2016 leading to food shortages and livestock

deaths and where humanitarian help has been organized. Indeed, in February 2018 the government of Kenya declared the drought a state of emergency as 2,7 million inhabitants were food insecure (Okal et al, 2020).

Nevertheless, Jarso Ibrahim Gollole, pastoralist and natural resource advisor of the NGO Mercy Corps mentioned how drought responses of Kenyan government were successful and even attracting communities of neighbouring countries[11].

Water availability is a key factor and although all efforts have been made to plant the trees at the right period, water is still an issue and varies from year to year. In Kenya most of the farmers are rainfed (Ochieng, 2016).

Tree species & location

In 2017, *Mangifera indica* and *Azadirachta indica* were the most popular tree species chosen by the farmers, in 2018 it was again *Mangifera indica* seconded this time by *Melia volkensi*.

From the comparison of the survival rate of tree species between the two years, some species have been more affected by the lack of rain in the first year of the project. These are *Carica papaya*, *Melia volkensii* and *Moringa oleifera* and to lesser extend *Mangifera indica. Senna siamea* was not much affected by the different weather and *Azadirachta indica* performed better in the dry year (of this project). *Azadirachta indica* was also the tree specie where the trunk diameter was less in 2018 than in 2017, probably a pest or disease affected particularly *Azadirachta indica*.

The survival rates in the different sub-counties did not lead to a trend between the two years that could help defining a different tendency of any sub-county.

The information about altitude showed that higher altitude plots, above 1100 m, had a lower tree survival in 2018. Those higher altitude plots were mainly

11 https://www.mercycorps.org/were-we-work/kenya

located in the Machakos county, where altitude values are around 1200 m meanwhile the sub-counties of Kitui and Makueni are mainly at altitude between 800 and 1000 m. Regrouping the survival rate of the sub-counties as per the Table 4 showed that Machakos had a similar survival rate as the rest of the counties in 2017 but meanwhile the survival rate increased in Makueni and Kitui between 2017 and 2018, it kept relatively constant in Machakos, which leads to an under-average survival rate in Machakos in 2018. Nevertheless, each sub-county within Machakos had a different behaviour: Mwala increased its survival rate from 36,0% to 43,0%, Yatta kept a similar survival rate from 30,4% in 2017 to 29,9% in 2018, and Masinga got a decrease of the survival rate from 34,5% to 31,5%. The Yatta sub-county have a higher influence on the Machakos survival rate due to the higher quantity of trees. So, there is not clear conclusion, expect to continue observing if higher altitude would lead in lower survival rate in a rainy year or depending from another factor.

Additionally all trees species have been investigated at lower altitudes (1100 m or below) and at higher altitudes (above 1100 m) and there is no sign that a species would perform better at lower or higher altitude.

Concerning the farmer’s choice on tree species, there is no recognizable trend that some tree species would be more likely to be chosen in one sub-county as it was also quite different in the second year.

Interesting information is nevertheless that smaller quantities of donated trees (e.g. 7 pieces) led to a higher survival rate than bigger quantities such as 14 or even 21 seedlings. It raise the question if farmers have the capacity to manage higher amount of seedlings in the same year.

About the niches there is also not a clear statement that a special type of niche would lead to certain better survival rate. Also, the information from the biplots would need further confirmation. So, from this data it is convenient to let the farmers chose the niches according to their circumstances and experience.

Tree management practices

The planting hole diameter does not lead to a clear statement either. Bigger planting holes seems to be slightly more advantageous but not the leading factor for tree survival. Also, it can be related to the probability that stunted seedlings with low survival chances got a smaller hole as farmers may not have seen the advantages to spend too much time digging. In the second year the majority of the holes were 'big' meanwhile in 2017 the majority were '2X' with a smaller quantity of '3X', so that probably farmers had a higher tendency to answer 'big' where no measurements was mentioned.

Manure and mulch applications showed that when the farmer already applied manure, the application of mulch did not bring any improvement to the survival rate (2017) or even reduced it (2018). So, the recommendation is not to combine manure and mulch, and in case both are available manure has to be preferred due its higher survival rate than mulch in both years. Also, in 2018, the application of mulch alone was more successful than manure and mulch together.

The second year, more farmers applied manure only (38,9% in 2018 for 32,7% in 2017), but also more farmers which did not apply anything (39,4% instead of 23,7% in 2017), one explanation could be the dry previous year leading to less resources. If more manure alone would have been applied in 2018, then the survival rate could have been even higher.

Nevertheless, manure and mulch can also be a source of pest or disease as the farmers mentioned in the notes.

Moringa oleifera profited the most of watering, followed by *Azadirachta indica* and *Melia volkensii.* In the previous paragraph, this was *Carica papaya*, *Melia volkensii* and *Moringa oleifera* and to lesser extend *Mangifera indica* who profited most from the rainfall in the second year. So that *Moringa oleifera* and *Melia volkensii* profits from watering and rainy years. But *Azadirachta indica* performed better in the dry year which is a contradiction with its better performance with watering, as mentioned earlier it could be related to pests and diseases.

Senna siamea was not much affected by the different weather in the two years and also got a similar survival rate with watering or without watering, so *Senna siamea* is less sensitive to lack of water than the other species. The only contradiction is that farmers watered *Senna siamea* more often than the other species. It could be interesting to ask the farmers why.

The different reasons why farmers did not water is showing that farmers are not always expecting high workload with the trees, some farmers expect trees to grow without watering and that the rainy season is enough. Otherwise some answers showed some shortages such as water/ water price or available manpower. Usually the farmers watered the trees once a week although the best survival rate was reached by farmers with daily tree watering.

This is a reminder that tree management is work and resource intensive and this need to be considered while implementing agroforestry projects.

The fencing is showing a slightly higher survival rate increase, from 42,1% considering all trees to 46,9% for protected trees, than watering which reached 46,2%. And all tree species benefited. This is to relate with the many trees that have been destroyed by livestock as it has been mentioned many times by the farmers in the open questions of survey.

The trees that profited most of shade, *Carica papaya* and *Mangifera indica*, are not the same trees than those who showed improvement in survival rate with rain or water, which were *Moringa Oleifera* and *Melia volkensii*.

Only *Senna siamea* had a higher mortality rate with shade which can be related with the previous understanding that the tree does not need as much water as other species and therefore a lot of sun. But only few *Senna siamea* got shade (3,2%) so a more robust result would be needed.

Reasons for non-survival

For 2017, the notes given by the farmers at the end of the interview for the trees which did not survive, have been considered. Although the question was not explicitly about the non-survival, this was mainly what the farmers were looking forward to say. This gives a room outside of the structured interview and information given here is very precious. The main mentioned reason for trees to die are pests and diseases with a special emphasis on pests such as ants, termites and worms. This is new in the survey as there were no questions about pests and diseases earlier. Ants and termites are in fact very common insect groups that can be found in almost every continent except the Antarctica, they are key factors for soil structure and have a regulating function (Whitford & Eldridge, 2013). Then a second big reason is drought, water scarcity and high temperatures, which was up to now recognized as a major factor of non-survival. Then the third category is seedling quality or size that can be also be grouped with seedling transportation, where farmers received a seedling with low survival chances. A fourth category is livestock damages, that can be related to the improvement through fencing seen earlier. A category is called cold spells but as minimum temperature is not below 15°C in this region, trees are sensitive to temperatures.

In 2018 the farmers had to choose different non-survival categories: drought (mentioned by 43,6% of the farmers), pests (35,2%), damage from livestock (26,3%), poor seedling quality (20,7%) & diseases (19,9%). The pests and diseases – if added together – is again the main reason for non-survival.

Solutions against lack of water can be rain water harvesting or reducing tillage or increasing soil organic matter (Porter & Francis). The environmental suitability of agricultural pests and diseases is subject to increase in the tropics due to climate change (Reppin et al, 2020). Integrated pest management (IPM) strategies need then to be considered considering all crop and trees on the field, external inputs will be considered only if other strategies failed (Porter & Francis, 2017).

Tree species and ecosystem services

Ecosystems services of trees on farms

The ecosystem services list provide a very positive image of tree on farms and this is also widely accepted that agroforestry practices should be encouraged.

Nevertheless, there is also an unavoidable concurrence with crops on land, water, nutrients, light and labour; this means that ecosystem services of trees on farm cannot be simply added to the ecosystem services of the associated crops or pasture (Nyberg et al, 2020; Reppin et al, 2020).

Organic matter has a different position because it can be added from the tree to the soil in form of litter (Nyberg et al, 2020). That has been also confirmed in the Agroforestree Database (Orwa et al, 2009) where it is mentioned that *Mangifera indica* leaves increase soil fertility when used as mulch.

The allelopathic effects of tree to crops (Karauka, 2015) and pest and diseases need also to be considered. Additionally, *Azadirachta indica* and *Mangifera indica* have been mentioned by the farmers of the study of Karauka (2015) as having negative effects on soil fertility. Also, the publication of Rosenstock et al (2019) mentions how agroforestry interacts with human health but with an overall positive impact.

Tree on farms bring so much positive effects for the environment and the livelihoods of the local population, that it makes sense not to let smallholder farmers alone. Trees on farm have many indirect and non-use values such as carbon sequestration (Reppin et al, 2020) or landscape restoration, which profit the whole society.

Therefore, there is a need for incentive policies and subsidizing of tree planting. In the thesis of Kurauka (2015), the author recommends the key stakeholders to give out policies with the incentive of fast-growing trees for improved livelihood and soil fertility. Nevertheless, the author is mourning that despite a lot of incentives for the farmers since independence to extend the areas dedicated to agroforestry, the expected rise is not taking place due to inadequate policies and legal constraints.

Tree species of the project

Appropriate tree species depends on many factors such as location, farmer management techniques, climate that varies from year to year, soil properties, other products on farms… Reppin et al (2020) mentions, for Western Kenya, variation in local environmental conditions for distance lower than 12 km.

Melia volkensii is the only indigenous tree of the project. Three species are from Asia and three species are from America. So, one aim of the project is to implement exotic species to enhance the potential of agroforestry landscapes. Kurauka (2015) mentions that exotic tree species are promoted threatening the existence of indigenous species. Exotic species for timber production presents a trade-off between profitability and preservation of the environment (Reppin et al, 2020).

Tree species have different lifetimes from *Carica papaya* bringing the first fruits already in the first year but lasting maximum five years to *Azadirachta indica* needing at least ten years to start bringing fruits but can live up to 200 years.

The sun/ light requirements and sensitivity/ resistance of the different tree species as per the database match only partially with the conclusions made earlier in this chapter. The matching conclusions are for instance, *Senna siamea* that needs light and was affected negatively by shade, or *Moringa oleifera* that profits from water supply and has a recommended location near rivers or high-water table. Nevertheless, the analysis of the interviews is not enough to make general conclusions on species requirements.

Additionally, Kurauka (2015) mentions that inadequate tree species are planted in areas, which are ecologically not adapted. This is also mentioned in Bourne et al. (2019) that one reason of the non-survival is ecologically unsuitable tree species. The report mentions that it is important to understand the choice of the farmers for specific species.

As per the paper of Kindt et al (2006) tree species diversity do not only need to be done from the taxa point of view but also from the products they provide. The study of McMullin et al (2019), brings an important aspect related to the decision on adequate tree species in relation to food security: namely which are the fruits that can bring vitamins during the dry months? In Machakos the dry period goes from August to December as per the study. *Carica papaya* and *Mangifera indica*, both source of Vitamin A and C are providing fruit during those food insecure months, especially *Carica papaya* producing fruit already from October meanwhile the mangos ripen starting from December. Other fruit trees worth mentioning are *Balanites aegyptiaca* with desert dates rich in vitamin C available in August and September, or *Passiflora edulis* producing passion fruit with content in vitamins A and C available in October.

Decisions on tree planting & species

The farmers decided mostly by themselves the tree species as only 6% of the households mentioned external involvement in their decision. Nevertheless, as the project provided seven species, they had this restriction in their choice.

As per Kindt et al (2006), there is a concern about tree diversity in agricultural landscape as there is not enough exchange of tree seedlings between villages, so that species within a village tend to keep over the years.

Farms with male or female household heads have a very similar seedling species' choice. The very small difference could be that fruit trees have been slightly more often chosen by female household such as *Carica papaya* (3% instead of 2% in a male household) and *Mangifera indica* (44% instead of 40%) meanwhile male households had a preference for *Azadirachta indica* (18% instead of 15% in a female household) and *Melia volkensii* (23% instead of 20%) providing wood.

One reason, why results are similar, is that many decision processes are taken between husbands and wives and the ownership of the farm is not the key factor.

Although 372 households planted additional trees in the last 12 months, 1082 households are planning to do so in the next 12 months. Again, there is an optimism as the following year is supposed to bring more opportunities than the previous one. Most of the farmers, who planted trees in the last 12 months, planted 10 trees or less, for the next 12 months the majority of the farmers are planning up to 20 trees, which is again more ambitious. This optimism is an asset.

Farmers, who planted their own additional trees, chose between more than 70 different species but with a prevalence on the seven species of the project (*Calliandra calothyrsus* to a lesser extend). *Cassia singueana* (Mikengeta in Swahili) is the tree species that is not part of the project but which showed also a high interest from the farmers.

In their article, Franzel et al (2014) have found that *Calliandra calothyrsus* as fodder can improved the milk production by 0,6–0,75 kg per kilogram of dried fodder. *Calliandra calothyrsus* is also the primary fodder shrub promoted by Vi Agroforestry, the Swedish NGO in Hughes et al (2020).

There are much more tree species that is of interest in Kenya. For instance, in the study of Kurauka (2015), farmers of Kitui Central recommend *Melia volkensii, Acacia spp.*, *Croton and Sesbania sesban*. They also recommended exotic species such as *Calliandra Calothyrsus*, *Senna siamea*, *Grevillea robusta*.

Grevillea robusta has been promoted by the Kenyan government as it is considered a multi-purpose tree not competing with other crops and make it suitable to an agroforestry system as for instance in a coffee plantation. (Kurauka, 2015)

Households participating on both years

In the 2018 survey, 70% of the households were already involved during the previous year in the project and could use that experience in their choice, however survival rates for those farmers were not above average. So there are other factors leading to tree mortality than the experience of the farmers, or said differently the expertise of the farmers did not change enough during the two years that it could be reflected in the survival rate. Nevertheless, farmers feel confident in learning from the practice as they mention their increasing knowledge as a reason for the better survival in 2018 (Bourne et al, 2019).

Very few trees were already in production after 1,5 years, which is not surprising as only according the data summarized in Table 15 only *Carica papaya* may be able to produce fruits in this short time. Nevertheless the farmers mentioned many products and services for instance from leaves.

The dropping interest of second-year farmers in *Senna siamea* (7% versus 19,1% of first-year farmers) cannot be explained by the survival rate as it was highest in 2017 and the survival rate of *Moringa oleifera* in 2017 was below average, this does not explain the increase in interest of the second-year farmers (7,3% versus 3,2% of first-year farmers).

CHAPTER 5 CONCLUSION

The first objective of this study was to gain an understanding on farmer households' circumstances by reviewing the socio-economic data and how it can influence the uptake of agroforestry. The data from the households were manifold and bring a lot of insights into the situation of the farmers also including their aspirations. How to consider those circumstances while implementing agroforestry practices, is more subtle. As trees on farms are work intensive, older farmers need more support to maintain their trees. The farmer owners were more often men, but tree planting work was more often done by women so that both men and women need to be involved in trainings or new projects. Land tenure seemed to be secure and there is no high migration wish. Best tree survival rates were reached by farmers having from 2 to 10 hectares of land at disposition, meanwhile the farmers receiving less trees (7 trees seedlings instead of 14 or 21) reached a better survival rate; food is not always available in quality and quantity but farmers were confident about future and food aid was provided.

The second objective about the key factors for the survival of planted trees is only partially met. Although quite a lot of factors have been compared there is only one very important factor which is the rainfall quantity in that season (October to December). Also, differentiation by species or by sub-counties or location were not clearly conclusive. The lower survival rate at higher altitudes (Machakos) was only true in 2018. From the tree management practices, the really interesting result was that applying manure and mulch together was reducing the survival rate, so that an application of manure only or mulch only is preferable. Watering and fencing were definitively improving the survival rate but values were still below 50%. Shade was profiting *Carica papaya* and *Mangifera indica. Senna siamea* proved to be the most stable between the two years, without much need of additional water and reacting negatively to shade.

Concerning the farmer's comment on non-survival of trees, pests and diseases, especially ants and termites, was the biggest concern.

Finally, the last objective about the seven species and their contribution to improve livelihood and maintain ecosystem services with their products and services is the most difficult one. It is not possible to find a clear connection between the tree species of the project and the information of the agroforestree database. For their own purchase farmers are planting many tree species including those of the projects. Gender of household head did not clearly affected the choice of the species and the farmers, who participated in the projects twice, did not achieve a better tree survival rate at the second time.

The limitations for this work are various. On one hand the interviews were prepared by professionals integrating their expertise which was very helpful. On the other hand, this report had some objectives, like gender differences or affinity of farmers to special tree species or products & services from previous trees, that were addressed only partially by the interviews. At least it shows how important it is to formulate one's objectives before starting interviews. Then, travel restrictions in Kenya starting from end of March 2020 made it impossible to travel to the area, which would have definitively helped to get more insights about farmers' lives, tree species or local economic situation. Finally, more time would have allowed to deepen more the results section comparing more data and using more refined statistic methods. Also, more time would have allowed to enhance the literature research, especially on the tree species or the application of manure combined with mulch.

The recommendation to be given to the farmers are few, that the trees needs manure, water and fences. For the other stakeholders, one proposal can be discussed that covers two topics at once. At first, trees are really needed to restore the landscape, avoid desertification and providing better living space for the local population. It is somehow not fair and also risky to give the entire responsibility of planting and maintaining trees on farm to smallholder farmers, especially knowing that many of them live in precarious situations not having always access to healthy food or health care. The maintenance of trees on farm is a work intensive and requires resources, farmers need more security of a return on investment. In many cases there will be no return at all as trees will not survived, but also in other cases it will take years to be able to profit of products or services of the trees. The farmers need a compensation for the service they provide to the society. The second aspect concerns the climate variations that lead to uncertain agricultural revenues. As those climate variations are somehow connected to the earth warming through greenhouse gases, it could be a solution that the CO_2 emitters pay a tax for their emissions and this is how the farmers could be paid to plant trees. As this may not be applicable immediately, a first step is to ensure programmes and policies adequate for farmers to get encouraged to plant trees. Additionally, appropriate support needs to be provided to ensure tree survival, for instance in the form of water supply or free manpower to install tree fencing.

Further works could be first to continue the analysis of the data contained in the surveys, there is still some potential of combining different entries that would lead to additional conclusions, for instance the tree diversity within a niche or the tree survival rate for farmers, who purchased additional trees. Also, a study could be done at village level instead of differentiating by sub-counties. Then in a second step external data of the areas such as more detailed climate data, soil properties, geomorphological or watershed informations can be gathered and be related with the entries of the interviews.

Also data of a third year could enhance the knowledge, to identify more clearly the trends. Although the question here would be that, in case the project get repeated, what can be done differently? Is it appropriate to continue planting with seedling survival rate below 50%, especially knowing that the two years of the project were above average if compared with the rainfall quantities of the previous and following years.

Another area of work would be to study the seedlings at delivery, what are their probability to survive if the conditions were optimal? Which nurseries are providing best quality? Another topic can also be to deepen the understanding on pest and diseases.

Another task could be the study of the policies in Kenya and understand how it affected the extension of agroforestry. A more challenging task could be to try to quantify the costs and incomes from specific tree species on farms to calculate the return on investment for the farmer but also for the society considering also the indirect and non-use benefits.

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Appendices

Appendix 1 Climate data in Makindu (Makueni) and Mutomo (Kitui)

The following information is extracted from www.en.climate-data.org:

Makindu (Makueni county), is classified BSh in the Köppen-Geiger climate classification (hot semi-arid). The average annual temperature is 22,5°C and the annual precipitation about 614 mm. The altitude is about 993m above sea level.

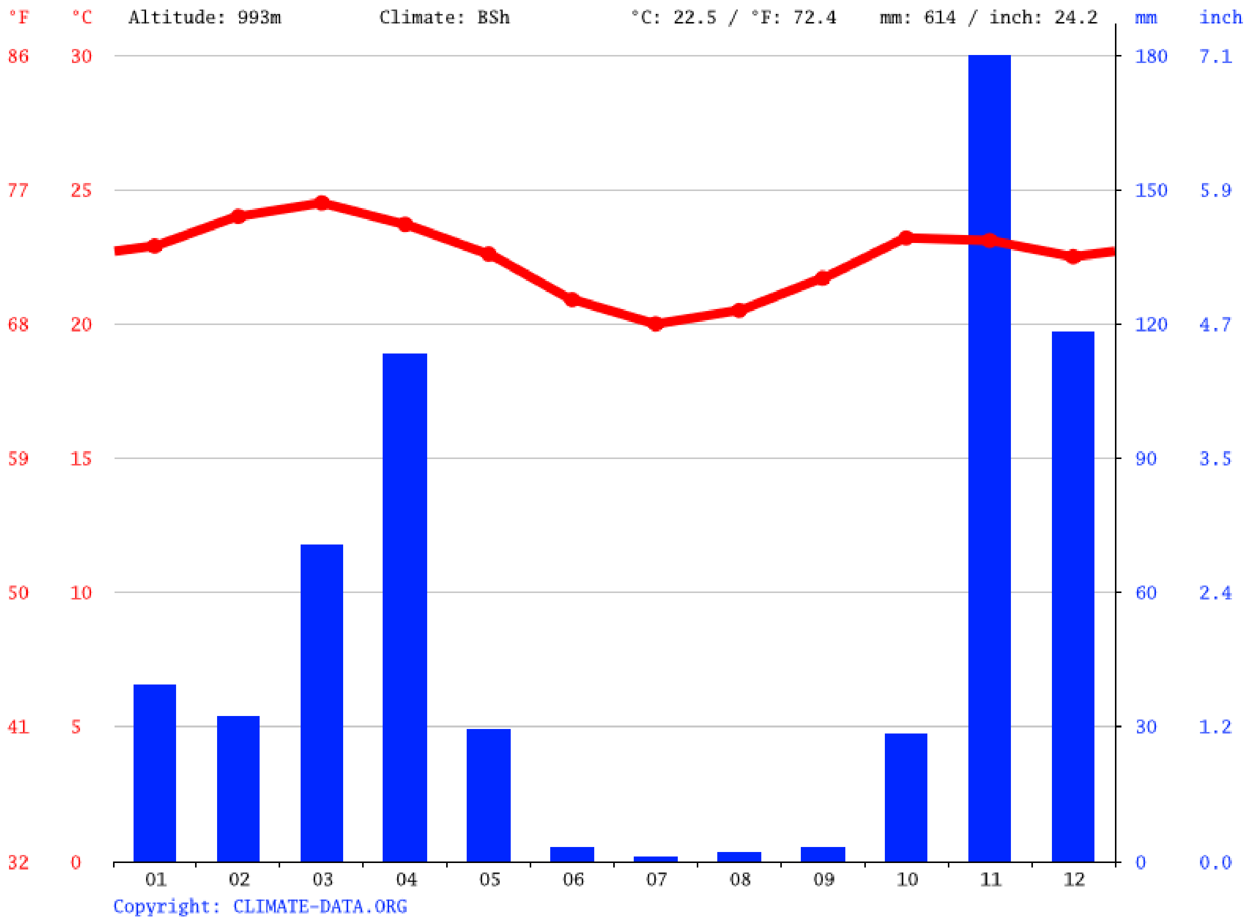

Figure 42: Precipitation and average temperature per month in Makindu (Makueni)

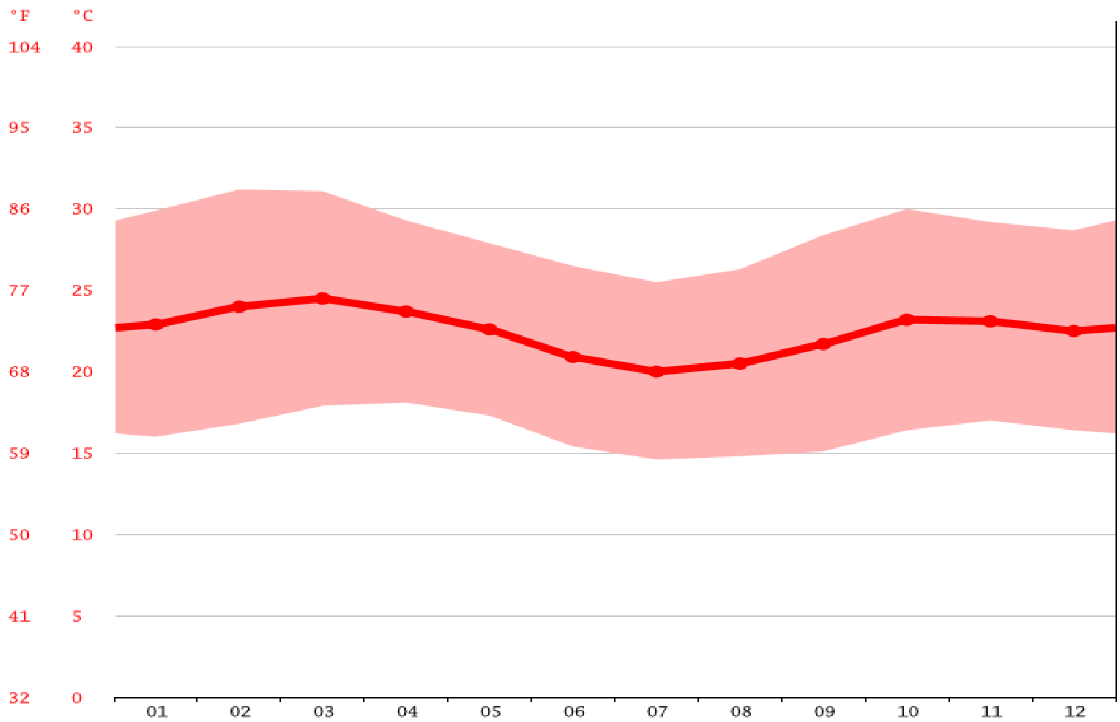

Figure 43: Minimum, average and maximum temperatures per month in Makindu (Makueni)

Mutomo (Kitui county), is also classified hot semi-arid (BSh in the Köppen-Geiger climate classification). The average annual temperature is 23°C and the annual precipitation about 676 mm. The altitude is about 896 m above sea level.

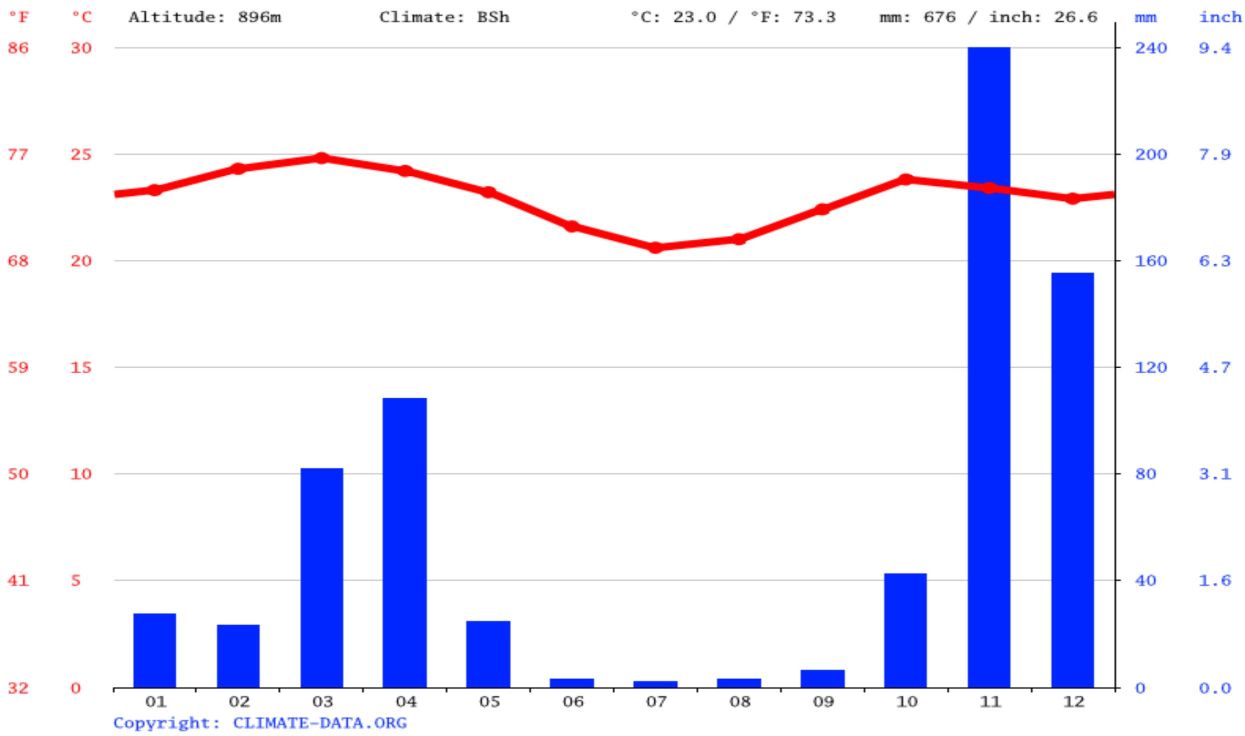

Figure 44: Precipitation and average temperature per month in Mutomo (Kitui)

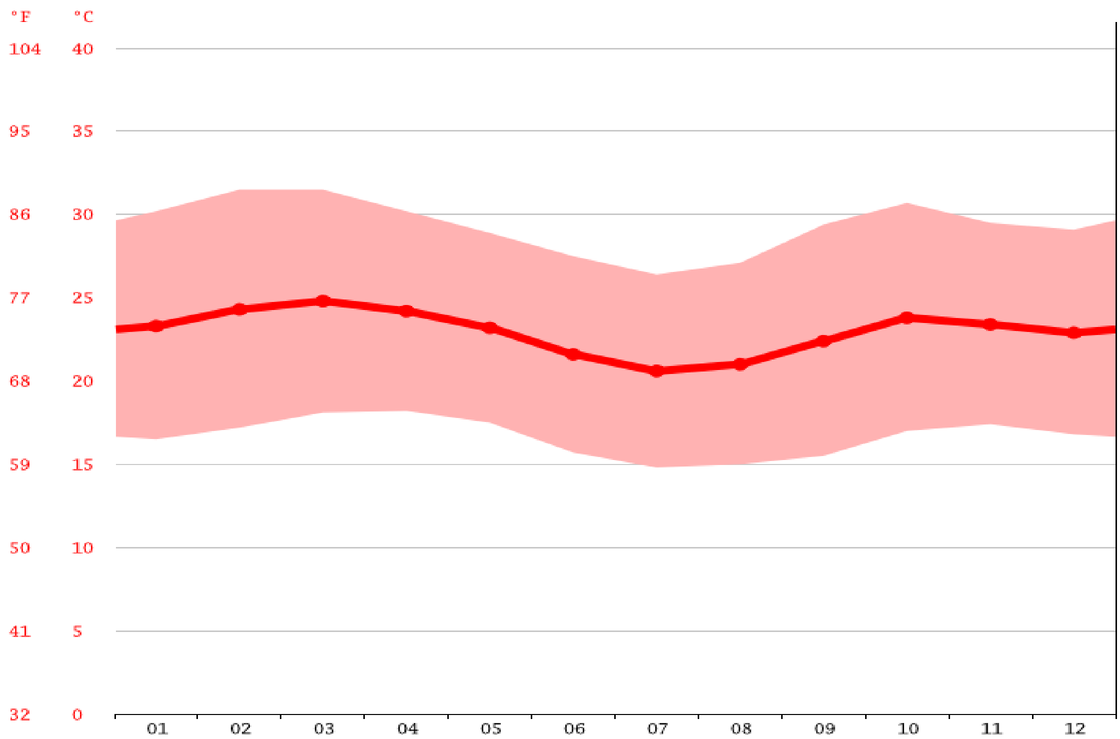

Figure 45: Minimum, average and maximum temperatures per month in Mutomo (Kitui)

Appendix 2 Element description 'Tree planting data 2017' & 'Tree planting data 2018'

Tree planting data 2017- Kenya: DataDictionary_ElementDescription.csv

(Source: Magaju et al, 2019a)

<table>
<tr><th>Element_DisplayName</th><th>Description</th><th>Unit</th><th>Data_type</th><th>Character_Length?</th><th>Acceptable_Values?</th><th>Required?</th><th>Accepts_NullValue?</th></tr>
<tr><td>1 HH_ID</td><td>Identification code of the household (HH). The HH_ID is randomly generated from a numeric code automatically assigned to each survey.</td><td>NA</td><td>numeric</td><td>255</td><td>NA</td><td>y</td><td>n</td></tr>
<tr><td>2 Data_Cat</td><td>The variable defines the type of data included inside the dataset: tp = tree planting data</td><td>NA</td><td>text</td><td>255</td><td>tp</td><td>y</td><td>n</td></tr>
<tr><td>3 File_Version</td><td>The variable defines the version of the survey utilized</td><td>NA</td><td>text</td><td>255</td><td>New | Old</td><td>y</td><td>n</td></tr>
<tr><td>4 County</td><td>County of the survey</td><td>NA</td><td>text</td><td>255</td><td>Kitui | Machakos | Makueni</td><td>y</td><td>n</td></tr>
<tr><td>5 Sb_County</td><td>Sub-county of the survey</td><td>NA</td><td>text</td><td>255</td><td>Kibwezi East | Kitui Rural | Masinga | Mbooni | Mwala | Mwingi Central | Yatta</td><td>n</td><td>y</td></tr>
<tr><td>6 Ward</td><td>Ward of the survey</td><td>NA</td><td>text</td><td>255</td><td>Ekalakala | Invingoni/Nzambani | Kalawa | Kanyangi | Makutano/Mwala | Masongaleni | Matuu | Mtito Andei | Ndalani | Waita</td><td>n</td><td>y</td></tr>
<tr><td>7 Loc</td><td>Location of the survey</td><td>NA</td><td>text</td><td>255</td><td>Endui | Ikaatini | Ikatini | Kalulini | Kanyangi | Katangini | Kathekani | Kathulimbi | Matuu | Mwala | Ndauni | Ngwata | Nthogoni | Nzambani | Waita</td><td>n</td><td>y</td></tr>
<tr><td>8 Sb_Loc</td><td>Sub-location of the survey</td><td>NA</td><td>text</td><td>255</td><td>Ikaatini | Ititu | Kakumini | Kaluluini | Kathekani | Kathongo | Katitika | Katulani | Kibau | Kivingoni | Kyawango | Lower Mukaange | Mandongoi | Mang'Elete | Masimba | Matuu | Mutembuku | Muthingini | Myanyani | Ngomoni | Ngulini | Nyaanyaa | Nzeveni | Syomunyu | Syotuvali | Thonoa | Waita | Yatta</td><td>n</td><td>y</td></tr>
<tr><td>9 Village</td><td>Village of the survey</td><td>NA</td><td>text</td><td>255</td><td>Athi | Chambiti | Changamwe B | Ikatini | Ikongeni | Ilondu | Isaani | Itangini | Kaliluni | Kalima | Kambili | Kambuu | Kamutonye | Kanduu | Kaseve | Katanga | Kathangathini | Kathiani | Katithi | Kativani | Katothya | Katulye | Kaunguni | Kavete | Kavumbuni | Kavuthu | Kikule | Kiliku | Kimutwa | Kithetheesyo | Kithiani | Kitie | Kitoto | Kitumbini | Kitwamikeu | Kiuanzukini | Komboyoo | Kwa Kutu | Kwandula | Kwanguli | Kyaani | Kyanganga | Kyangi | Kyulu | Kyusyani | Likoni | Makutano | Makutano B | Malumani | Maongoa | Masimba | Masimba A | Matiliku | Mbemba Imwe | Mbenuu | Mbetwani | Mbusyani | Miambani | Miangeni | Mikameni | Mililuni | Mukelenzu | Mukuku | Mutembuku | Mutkya | Muumbuni | Muunguu | Muuo | Mwaani | Mwitasyano A | Ndindi | Ndivu | Ndulumoni | Ngoa | Ngolomoto | Ngomano | Ngomeni | Nguuma | Nguumo | Nthunguni | Nzalani | Nzambani | Syomunyu | Syongungi | Thonoa | Uiini | Ulaani | Yatta | Yimuage | Yumbuni</td><td>n</td><td>y</td></tr>
<tr><td>10 Species_ID</td><td>Identification code of the tree species</td><td>NA</td><td>numeric</td><td>255</td><td>[1, 42]</td><td>y</td><td>n</td></tr>
<tr><td>11 Tree_Species</td><td>Scientific name of the tree species</td><td>NA</td><td>text</td><td>255</td><td>Azadirachta_indica | Carica_papaya | Mangifera_indica | Melia_volkensii | Moringa_oleifera | Senna_siamea</td><td>y</td><td>n</td></tr>
<tr><td>12 Planting_Date</td><td>Date of the planting</td><td>YYYYMMDD</td><td>date</td><td>255</td><td>NA</td><td>y</td><td>n</td></tr>
<tr><td>13 Niche</td><td>The variable defines the planting location inside the farm, choosing between: Ex_Boundary = external boundary; In_Boundary = internal boundary; Scattered = scattered in cropland; Woodlot; Home_Compound; Along_Terraces; Other</td><td>NA</td><td>text</td><td>255</td><td>Ex_Boundary | In_Boundary | Scattered | Woodlot | Home_Compound | Along_Terraces | Other</td><td>y</td><td>n</td></tr>
<tr><td>14 Other_Niche</td><td>The variable provide additional information about the planting location, in case it corresponds to other</td><td>NA</td><td>text</td><td>255</td><td>NA</td><td>n</td><td>y</td></tr>
<tr><td>15 Planting_Hole</td><td>The variable defines the type of planting hole used</td><td>NA</td><td>text</td><td>255</td><td>2X | 3X | Other</td><td>y</td><td>n</td></tr>
<tr><td>16 Other_Planting_Hole</td><td>The variable defines the diameter of the planting hole, in case the type correspond to other</td><td>cm</td><td>numeric</td><td>3</td><td>[1, 124]</td><td>n</td><td>y</td></tr>
<tr><td>17 Manure</td><td>The variable defines if farmyard manure was applied to the tree during the six months after the planting: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1</td><td>0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>18 Mulch</td><td>The variable defines if mulch was applied to the tree during the six months after the planting: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1</td><td>0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>19 Watering</td><td>The variable defines if watering was provided the tree during the six months after the planting: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1</td><td>0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>20 Survival</td><td>The variable defines the survival of the tree six months after the planting: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1</td><td>0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>21 Height</td><td>Height of the tree six months after the planting</td><td>cm</td><td>numeric</td><td>255</td><td>[0.27, 450]</td><td>n</td><td>y</td></tr>
<tr><td>22 Diameter</td><td>Diameter of the tree six months after the planting</td><td>cm</td><td>numeric</td><td>255</td><td>[0.02, 101]</td><td>n</td><td>y</td></tr>
<tr><td>23 Hours_Digging</td><td>The variable defines the number of hours dedicated to digging planting hole</td><td>hours</td><td>numeric</td><td>1</td><td>[0, 20]</td><td>n</td><td>y</td></tr>
<tr><td>24 Hours_Applying_Treatments</td><td>The variable defines the number of hours dedicated to applying treatments to the tree during the six months after the planting</td><td>hours</td><td>numeric</td><td>1</td><td>[0, 5]</td><td>n</td><td>y</td></tr>
<tr><td>25 Watering_Frequency</td><td>The variable defines the frequency of watering</td><td>NA</td><td>text</td><td>255</td><td>Daily | Weekly | Bi-Weekly</td><td>n</td><td>y</td></tr>
<tr><td>26 Hours_Watering</td><td>The variable defines the number of hours dedicated to watering the tree during the six months after the planting</td><td>hours</td><td>numeric</td><td>1</td><td>[1, 50]</td><td>n</td><td>y</td></tr>
<tr><td>27 Pruning</td><td>The variable defines if the tree is pruned: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1</td><td>0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>28 Hours_Pruning</td><td>The variable defines the number of hours dedicated to pruning the tree during the six months after the planting</td><td>hours</td><td>numeric</td><td>1</td><td>[1, 5]</td><td>n</td><td>y</td></tr>
<tr><td>29 Notes</td><td>Additional observation about the tree planting. The information were transcribed as stated by teh farmer and partially harmonized for analysis purpose</td><td>NA</td><td>text</td><td>255</td><td>NA</td><td>n</td><td>y</td></tr>
</table>

Tree planting data 2018 -Kenya: DataDictionary_ElementDescription.csv

(Source: Magaju et al, 2019b)

	Element_DisplayName	Description	Unit	Data_type	Character_Length?	Acceptable_Values?	Required?	Accepts_NullValue?
1	HH_ID	Identification code of the household (HH). The HH_ID is randomly generated from a numeric code automatically assigned to each survey.	NA	numeric	255	NA	y	n
2	DataCollector_ID	Identification code for the data collector. Each data collector is anonymize for privacy reason and identified by a capital letter or a capital letter sequence. The ID is provided only as a control measure for the reliability of the collected data.	NA	text	1	[C, BU]	y	n
3	Date	Date of the survey	YYYYMMDD	date	255	NA	n	y
4	Profiling	The variable defines if someone from the household has completed the farmer profile survey: 1 = yes; 0 = no	NA	numeric	1	[0, 1]	y	n
5	Prev_Monitoring	The variable defines if the household was involved in the last tree monitoring survey (December 2017): 1 = yes; 0 = no	NA	numeric	1	[0, 1]	y	n
6	HH_Head_Age	Age of household head	NA	numeric	2	NA	n	y
7	HH_Head_Gender	Gender of the household head. It is defined by a numeric code: 1 = male; 0 = female.	NA	numeric	1	0 | 1	y	n
8	Rel_HH_Head	Familiar relation of the interviewed farmer with the head of the household. The relation is defined by a numeric code: 1 = household head; 2 = first wife and only wife; 3 = spouse of household head; 4 = son/daughter of household head; 5 = grandchild of household head; 6 = parent of household head; 7 = nephew/niece of household head; 8 = other relative; 9 = Other.	NA	numeric	2	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9	y	n
9	Adult_Men	Number of adult men in the household	NA	numeric		[0, 8]	y	n
10	Labour_Men	Number of adult men in the household providing any amount of labour on the farm within the last 12 months	NA	numeric		[0, 8]	y	n
11	Adult_Women	Number of adult women in the household	NA	numeric		[0, 7]	y	n
12	Labour_Women	Number of adult women in the household providing any amount of labour on the farm within the last 12 months	NA	numeric		[0, 6]	y	n
13	Fs_Tot	Total amount of land the household had access to in the last 12 months	NA	numeric		[0, 30000]	y	n
14	Fs_Tot_Units	Unit of measurement of the land: 1 = square meters; 2 = Acres; 3 = Hectares	NA	numeric	1	1 | 2 | 3	y	n
15	Fs_Rent	The variable defines if any of the land the household had access to in the last 12 months was rented: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
16	Tot_Rent	Total amount of land the household rented in the last 12 months	NA	numeric		[0, 8]	n	y
17	Rent_Units	Unit of measurement of the rented land: 1 = square meters; 2 = Acres; 3 = Hectares	NA	numeric	1	1 | 2 | 3	n	y
18	Rent_Secure	The variable defines if the intervewed farmer thinks the household will be able to continue using the rented land for as long as they need: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
19	Fs_Borrow	The variable defines if any of the land the household had access to in the last 12 months was borrowed: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
20	Tot_Borrow	Total amount of land the household borrowed in the last 12 months	NA	numeric		[0, 5]	n	y
21	Borrow_Units	Unit of measurement of the borrowed land: 1 = square meters; 2 = Acres; 3 = Hectares	NA	numeric	1	1 | 2 | 3	n	y
22	Borrow_Secure	The variable defines if the intervewed farmer thinks the household will be able to continue using the borrowed land for as long as they need: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
23	Fs_Own	The variable defines if any of the land the household had access to in the last 12 months was owned by the household: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
24	Tot_Owned	Total amount of land the household owned in the last 12 months	NA	numeric		[0.25, 9]	n	y
25	Owned_Units	Unit of measurement of the borrowed land: 1 = square meters; 2 = Acres; 3 = Hectares	NA	numeric	1	1 | 2 | 3	n	y
26	LandTenure	Legal documentation the household holds for the land: 1 = title deed; 2 = allotment letter; 3 = other	NA	numeric	1	1 | 2 | 3	n	y
27	LandTenure_Others	The variable provide additional information about the legal documentation, in case it corresponds to other.The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
28	Owned_Secure	The variable defines if the intervewed farmer thinks the household will be able to continue using the owned land for as long as they need: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
29	Fs_Occupied	The variable defines if any of the land the household had access to in the last 12 months was under a different form of tenure (not owned, rented or borrowed): 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
30	Tot_Occupied	Total amount of land the household occupied in the last 12 months	NA	numeric		[0, 1]	n	y
31	Occupied_Units	Unit of measurement of the occupied land: 1 = square meters; 2 = Acres; 3 = Hectares	NA	numeric	1	1 | 2 | 3	n	y
32	Occupied_Secure	The variable defines if the intervewed farmer thinks the household will be able to continue using the occupied land for as long as they need: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
33	Num_Plots_Far	The variable defines if there are any plots located far away from the homestead: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
34	Dist_Far	Distance of the far away plots from the homestead	km	numeric	4	[0, 60]	n	y
35	Tot_Area_Far	Total amount of land inside the plots	NA	numeric		[0.5, 10000]	n	y
36	Far_Units	Unit of measurement of the plot land: 1 = square meters; 2 = Acres; 3 = Hectares	NA	numeric	1	1 | 2 | 3	n	y
37	Far_Trees	The variable defines if trees from the project were planted in the plots: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
38	Fs_Shenough	The variable defines if the seasonal harvest (April/May rains) is expected to be enough to cover your household's consumption needs: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
39	Fs_Surplus	The variable defines if a surplus is expected: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
40	Fs_Deficit_Plan.1	The variable defines if the household is expecting to cope with consuption deficit according to plan.1, corresponding to buy food at the market: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
41	Fs_Deficit_Plan.2	The variable defines if the household is expecting to cope with consuption deficit according to plan.2, corresponding to remittances: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
42	Fs_Deficit_Plan.3	The variable defines if the household is expecting to cope with consuption deficit according to plan.3, corresponding to government assistance/food aid: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
43	Fs_Deficit_Plan.4	The variable defines if the household is expecting to cope with consuption deficit according to plan.4, corresponding to sell assets: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
44	Fs_Deficit_Plan.5	The variable defines if the household is expecting to cope with consuption deficit according to plan.5, corresponding to other: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
45	Fs_Deficit_Plan_Other	The variable provide additional information about the deficit plan, in case it corresponds to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
46	Fs_FoodAid_5Year	The variable defines if the household received government assistance/food aid in the past 5 years: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
47	Fs_FoodAid_1Year	The variable defines if the household received government assistance/food aid in the last 12 months: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
48	Insufficient_Food	The variable defines if during the last 12 months, there was a time when the farmer was worried he would not have enough food to eat because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
49	Healthy_Food	The variable defines if during the last 12 months, there was a time when the farmer cannot eat healthy and nutritious food because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
50	Food_Options	The variable defines if during the last 12 months, there was a time when was possible to eat only a few kinds of foods because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
51	Skip_Meal	The variable defines if during the last 12 months, there was a time when the farmer had to skip a meal because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
52	Eat_Less	The variable defines if during the last 12 months, there was a time when the farmer ate less than necessary because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
53	Deplete_Food	The variable defines if during the last 12 months, there was a time when the household ran out of food because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
54	Fs_Hungry	The variable defines if during the last 12 months, there was a time when the farmer was hungry but did not eat because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
55	Fs_No_Food	The variable defines if during the last 12 months, there was a time when the farmer did not eat for a whole day because of a lack of money or other resources: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
56	Parents_Born	The variable defines if the parents of the interwieved farmer were born in the village where the survey takes place	NA	numeric	1	0 | 1	y	n
57	Farmer_Born	The variable defines if the interwieved farmer was born in the village where the survey takes place	NA	numeric	1	0 | 1	y	n
58	Years_Farming	Number of years faming in this village	NA	numeric	2	[0, 84]	y	n
59	Migrate	The variable defines if there are household members who now permanently live and earn their living elsewhere: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
60	Migrate_Male	Number of male household members migrated elsewhere	NA	numeric		[0, 8]	n	y
61	Migrate_Female	Number of female household members migrated elsewhere	NA	numeric		[0, 7]	n	y
62	Future_Migrate	The variable defines if there are household members who are planning or are expected to permantly move out of the household in the next 5 years: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
63	Future_Migrate_Male	Number of male household members expected to migrate elsewhere	NA	numeric		[0, 4]	n	y
64	Future_Migrate_Female	Number of female household members expected to migrate elsewhere	NA	numeric		[0, 4]	n	y
65	Past_Crop_Production	Crop production trend in the last 5 years: 1 = improve; 2 = decline; 3 = stayed the same	NA	numeric	1	1 | 2 | 3	y	n
66	Future_Crop_Production	Crop production trend expected in the next 5 years: 1 = improve; 2 = decline; 3 = stay the same	NA	numeric	1	1 | 2 | 3	y	n
67	Investment1	The variable defines if, having 25,000 KES available, the farmer would invests in choice 1, corresponding to start a business/shop: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
68	Investment2	The variable defines if, having 25,000 KES available, the farmer would invests in choice 2, corresponding to buy land: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
69	Investment3	The variable defines if, having 25,000 KES available, the farmer would invests in choice 3, corresponding to go to school: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
70	Investment4	The variable defines if, having 25,000 KES available, the farmer would invests in choice 4, corresponding to send children to school: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n

<table>
<tr><td>71</td><td>Investment5</td><td>The variable defines if, having 25,000 KES available, the farmer would invests in choice 5, corresponding to buy more livestock: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>72</td><td>Investment6</td><td>The variable defines if, having 25,000 KES available, the farmer would invests in choice 6, corresponding to improve the house: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>73</td><td>Investment7</td><td>The variable defines if, having 25,000 KES available, the farmer would invests in choice 7, corresponding to move to another village/town/city/county: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>74</td><td>Investment8</td><td>The variable defines if, having 25,000 KES available, the farmer would invests in choice 8, corresponding to plant more trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>75</td><td>Investment9</td><td>The variable defines if, having 25,000 KES available, the farmer would invests in choice 9, corresponding to other: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>76</td><td>Reason_Investment</td><td>Reason for the investment. The informarion was transcribed as stated by the farmer</td><td>NA</td><td>text</td><td>255 NA</td><td>n</td><td>y</td></tr>
<tr><td>77</td><td>Restoration_Options</td><td>Other land restoration/land management options the farmer would be interested in trying on his farm. The informarion was transcribed as stated by the farmer</td><td>NA</td><td>text</td><td>255 NA</td><td>n</td><td>y</td></tr>
<tr><td>78</td><td>Comments</td><td>Additional comments from the farmer. The information was transcribed as stated by the farmer</td><td>NA</td><td>text</td><td>255 NA</td><td>n</td><td>y</td></tr>
<tr><td>79</td><td>PCS_Decide_Dug1</td><td>The variable defines if the farmer dugs the holes and plant the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>80</td><td>PCS_Decide_Dug2</td><td>The variable defines if the farmer wife dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>81</td><td>PCS_Decide_Dug3</td><td>The variable defines if the farmer husband dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>82</td><td>PCS_Decide_Dug4</td><td>The variable defines if the farmer daughter dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>83</td><td>PCS_Decide_Dug5</td><td>The variable defines if the farmer son dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>84</td><td>PCS_Decide_Dug6</td><td>The variable defines if the farmer grandmother dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>85</td><td>PCS_Decide_Dug7</td><td>The variable defines if the farmer grandfather dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>86</td><td>PCS_Decide_Dug8</td><td>The variable defines if the farmer father dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>87</td><td>PCS_Decide_Dug9</td><td>The variable defines if the farmer mother dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>88</td><td>PCS_Decide_Dug10</td><td>The variable defines if the household head dugs the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>89</td><td>PCS_Decide_Dug11</td><td>The variable defines if other people dug the holes and plant the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>90</td><td>PCS_Decide_Dug_Group</td><td>Common working group composition: 1 = mainly men; 2 = mainly women; 3 = both men and women</td><td>NA</td><td>numeric</td><td>1 1 | 2 | 3</td><td>n</td><td>y</td></tr>
<tr><td>91</td><td>PCS_Decide_Dug_Hired1</td><td>The variable defines if mainly men are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>92</td><td>PCS_Decide_Dug_Hired2</td><td>The variable defines if mainly women are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>93</td><td>PCS_Decide_Dug_Hired3</td><td>The variable defines if both men and women are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>94</td><td>PCS_Decide_Dug_Hired4</td><td>The variable defines if children (<18 years) are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>95</td><td>PCS_Decide_Dug_Hired5</td><td>The variable defines if young adults (18-30 years) are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>96</td><td>PCS_Decide_Dug_Hired6</td><td>The variable defines if old peaople are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>97</td><td>PCS_Decide_Dug_Hired7</td><td>The variable defines if other peaople are part of hired labour: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>98</td><td>PCS_Decide_Dug_Other</td><td>Additional information about hole digging and hired labour. The information was transcribed as stated by the farmer</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>99</td><td>Manure_Who1</td><td>The variable defines if the farmer applies manure to the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>100</td><td>Manure_Who2</td><td>The variable defines if the farmer wife applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>101</td><td>Manure_Who3</td><td>The variable defines if the farmer husband applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>102</td><td>Manure_Who4</td><td>The variable defines if the farmer daughter applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>103</td><td>Manure_Who5</td><td>The variable defines if the farmer son applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>104</td><td>Manure_Who6</td><td>The variable defines if the farmer grandmother applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>105</td><td>Manure_Who7</td><td>The variable defines if the farmer grandfather applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>106</td><td>Manure_Who8</td><td>The variable defines if the farmer father applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>107</td><td>Manure_Who9</td><td>The variable defines if the farmer mother applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>108</td><td>Manure_Who10</td><td>The variable defines if the household head applies manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>109</td><td>Manure_Who11</td><td>The variable defines if other people apply manure to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>110</td><td>Minutes_Manuring</td><td>Minutes spent applying manure to the trees per application</td><td>minutes</td><td>numeric</td><td>4 [0, 1200]</td><td>y</td><td>n</td></tr>
<tr><td>111</td><td>Mulch_Who1</td><td>The variable defines if the farmer applies mulching to the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>112</td><td>Mulch_Who2</td><td>The variable defines if the farmer wife applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>113</td><td>Mulch_Who3</td><td>The variable defines if the farmer husband applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>114</td><td>Mulch_Who4</td><td>The variable defines if the farmer daughter applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>115</td><td>Mulch_Who5</td><td>The variable defines if the farmer son applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>116</td><td>Mulch_Who6</td><td>The variable defines if the farmer grandmother applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>117</td><td>Mulch_Who7</td><td>The variable defines if the farmer grandfather applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>118</td><td>Mulch_Who8</td><td>The variable defines if the farmer father applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>119</td><td>Mulch_Who9</td><td>The variable defines if the farmer mother applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>120</td><td>Mulch_Who10</td><td>The variable defines if the household head applies mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>121</td><td>Mulch_Who11</td><td>The variable defines if other people apply mulching to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>122</td><td>Minutes_Mulching</td><td>Minutes spent applying mulching to the trees per application</td><td>minutes</td><td>numeric</td><td>3 [0, 360]</td><td>y</td><td>n</td></tr>
<tr><td>123</td><td>Fertilizer_Who1</td><td>The variable defines if the farmer applies fertilizers to the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>124</td><td>Fertilizer_Who2</td><td>The variable defines if the farmer wife applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>125</td><td>Fertilizer_Who3</td><td>The variable defines if the farmer husband applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>126</td><td>Fertilizer_Who4</td><td>The variable defines if the farmer daughter applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>127</td><td>Fertilizer_Who5</td><td>The variable defines if the farmer son applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>128</td><td>Fertilizer_Who6</td><td>The variable defines if the farmer grandmother applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>129</td><td>Fertilizer_Who7</td><td>The variable defines if the farmer grandfather applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>130</td><td>Fertilizer_Who8</td><td>The variable defines if the farmer father applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>131</td><td>Fertilizer_Who9</td><td>The variable defines if the farmer mother applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>132</td><td>Fertilizer_Who10</td><td>The variable defines if the household head applies fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>133</td><td>Fertilizer_Who11</td><td>The variable defines if other people apply fertilizers to the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>134</td><td>Minutes_Fertilizing</td><td>Minutes spent applying fertilizers to the trees per application</td><td>minutes</td><td>numeric</td><td>3 [0, 120]</td><td>y</td><td>n</td></tr>
<tr><td>135</td><td>Water_Who1</td><td>The variable defines if the farmer waters the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>136</td><td>Water_Who2</td><td>The variable defines if the farmer wife waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>137</td><td>Water_Who3</td><td>The variable defines if the farmer husband waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>138</td><td>Water_Who4</td><td>The variable defines if the farmer daughter waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>139</td><td>Water_Who5</td><td>The variable defines if the farmer son waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>140</td><td>Water_Who6</td><td>The variable defines if the farmer grandmother waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>141</td><td>Water_Who7</td><td>The variable defines if the farmer grandfather waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>142</td><td>Water_Who8</td><td>The variable defines if the farmer father waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>143</td><td>Water_Who9</td><td>The variable defines if the farmer mother waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>144</td><td>Water_Who10</td><td>The variable defines if the household head waters the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>145</td><td>Water_Who11</td><td>The variable defines if other people water the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>146</td><td>Hours_Watering</td><td>Hours spent watering the trees per application</td><td>hours</td><td>numeric</td><td>3 [0, 440]</td><td>y</td><td>n</td></tr>
<tr><td>147</td><td>Fencing_Who1</td><td>The variable defines if the farmer waters the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>148</td><td>Fencing_Who2</td><td>The variable defines if the farmer wife fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>149</td><td>Fencing_Who3</td><td>The variable defines if the farmer husband fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>150</td><td>Fencing_Who4</td><td>The variable defines if the farmer daughter fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>151</td><td>Fencing_Who5</td><td>The variable defines if the farmer son fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>152</td><td>Fencing_Who6</td><td>The variable defines if the farmer grandmother fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>153</td><td>Fencing_Who7</td><td>The variable defines if the farmer grandfather fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>154</td><td>Fencing_Who8</td><td>The variable defines if the farmer father fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>155</td><td>Fencing_Who9</td><td>The variable defines if the farmer mother fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>156</td><td>Fencing_Who10</td><td>The variable defines if the household head fences the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>157</td><td>Fencing_Who11</td><td>The variable defines if other people fence the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>158</td><td>Minutes_Fencing</td><td>Minutes spent fencing the trees per application</td><td>minutes</td><td>numeric</td><td>3 [0, 800]</td><td>y</td><td>n</td></tr>
<tr><td>159</td><td>Pruning</td><td>The variable defines if the trees are pruned: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>y</td><td>n</td></tr>
<tr><td>160</td><td>Why_No_Prune</td><td>If trees are not pruned, the variable defines why. The information was transcribed as stated by the farmer</td><td>NA</td><td>text</td><td>255 NA</td><td>n</td><td>y</td></tr>
<tr><td>161</td><td>Prune_who1</td><td>The variable defines if the farmer waters the trees by himself: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>162</td><td>Prune_who2</td><td>The variable defines if the farmer wife prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>163</td><td>Prune_who3</td><td>The variable defines if the farmer husband prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>164</td><td>Prune_who4</td><td>The variable defines if the farmer daughter prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>165</td><td>Prune_who5</td><td>The variable defines if the farmer son prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>166</td><td>Prune_who6</td><td>The variable defines if the farmer grandmother prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>167</td><td>Prune_who7</td><td>The variable defines if the farmer grandfather prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>168</td><td>Prune_who8</td><td>The variable defines if the farmer father prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>169</td><td>Prune_who9</td><td>The variable defines if the farmer mother prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>170</td><td>Prune_who10</td><td>The variable defines if the household head prunes the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>171</td><td>Prune_who11</td><td>The variable defines if other people prune the trees: 1 = yes; 0 = no</td><td>NA</td><td>numeric</td><td>1 0 | 1</td><td>n</td><td>y</td></tr>
<tr><td>172</td><td>Prune_Frequency</td><td>Pruning frequency, expressed in times per year</td><td>NA</td><td>numeric</td><td>2 [1, 10]</td><td>n</td><td>y</td></tr>
<tr><td>173</td><td>Minutes_Pruning</td><td>Minutes spent pruning the trees per application</td><td>minutes</td><td>numeric</td><td>3 [0, 800]</td><td>n</td><td>y</td></tr>
<tr><td>174</td><td>PbTime_Farm</td><td>The variable defines if tree planting and tree management changed the overall amount of time spent working on the farm: 1 = increased time; 2 = decreased time; 3 = stayed the same</td><td>NA</td><td>numeric</td><td>1 1 | 2 | 3</td><td>y</td><td>n</td></tr>
</table>

175	PbTime_FarmInc	The variable defines if this change affected the farmer ability to perform other tasks: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
176	PbTime_FarmInc_Eff1	Increased time for earning extra off farm income: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
177	PbTime_FarmInc_Eff2	Increased time for child care/looking after elderly: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
178	PbTime_FarmInc_Eff3	Increased time for preparing food: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
179	PbTime_FarmInc_Eff4	Increased time for collecting water: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
180	PbTime_FarmInc_Eff5	Increased time for collecting fuel wooe: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
181	PbTime_FarmInc_Eff6	Increased time for looking after livestock: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
182	PbTime_FarmInc_Eff7	Increased time for leisure: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
183	PbTime_FarmInc_Eff8	Increased time for community activities: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
184	PbTime_FarmInc_Eff9	Increased time for tending to crops: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
185	PbTime_FarmInc_Eff10	Increased time for looking after poultry: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
186	PbTime_FarmInc_Eff11	Increased time for other tasks: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
187	PbTime_FarmInc_Eff_Other	Additional information about the affected task in case it correspond to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
188	PbTime_FarmDec_Eff1	Decreased time for earning extra off farm income: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
189	PbTime_FarmDec_Eff2	Decreased time for child care/looking after elderly: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
190	PbTime_FarmDec_Eff3	Decreased time for preparing food: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
191	PbTime_FarmDec_Eff4	Decreased time for collecting water: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
192	PbTime_FarmDec_Eff5	Decreased time for collecting fuel wooe: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
193	PbTime_FarmDec_Eff6	Decreased time for looking after livestock: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
194	PbTime_FarmDec_Eff7	Decreased time for leisure: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
195	PbTime_FarmDec_Eff8	Decreased time for community activities: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
196	PbTime_FarmDec_Eff9	Decreased time for tending to crops: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
197	PbTime_FarmDec_Eff10	Decreased time for looking after poultry: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
198	PbTime_FarmDec_Eff11	Decreased time for other tasks: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
199	PbTime_FarmDec_Eff_Other	Additional information the affected task in case it correspond to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
200	PCS_Decide_Who1	The variable defines if the farmer decides who is involved in tree planting by himself: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
201	PCS_Decide_Who2	The variable defines if the farmer wife decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
202	PCS_Decide_Who3	The variable defines if the farmer husband decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
203	PCS_Decide_Who4	The variable defines if the farmer daughter decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
204	PCS_Decide_Who5	The variable defines if the farmer son decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
205	PCS_Decide_Who6	The variable defines if the farmer grandmother decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
206	PCS_Decide_Who7	The variable defines if the farmer grandfather decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
207	PCS_Decide_Who8	The variable defines if the farmer father decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
208	PCS_Decide_Who9	The variable defines if the farmer mother decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
209	PCS_Decide_Who10	The variable defines if the household head decides who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
210	PCS_Decide_Who11	The variable defines if other people decide who is involved in tree planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
211	PCS_Decide_Who_Other	Additional information about who decides who is involved in tree planting in case it correspond to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
212	PCS_Decide_Spp1	The variable defines if the farmer decides which species of tree to plant by himself: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
213	PCS_Decide_Spp2	The variable defines if the farmer wife decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
214	PCS_Decide_Spp3	The variable defines if the farmer husband decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
215	PCS_Decide_Spp4	The variable defines if the farmer daughter decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
216	PCS_Decide_Spp5	The variable defines if the farmer son decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
217	PCS_Decide_Spp6	The variable defines if the farmer grandmother decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
218	PCS_Decide_Spp7	The variable defines if the farmer grandfather decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
219	PCS_Decide_Spp8	The variable defines if the farmer father decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
220	PCS_Decide_Spp9	The variable defines if the farmer mother decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
221	PCS_Decide_Spp10	The variable defines if the household head decides which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
222	PCS_Decide_Spp11	The variable defines if other people decide which species of tree to plant: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
223	PCS_Decide_Spp_Other	Additional information about who decides which species of tree to plant in case it correspond to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
224	PCS_Decide_Where1	The variable defines if the farmer decides where to plant the trees by himself: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
225	PCS_Decide_Where2	The variable defines if the farmer wife decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
226	PCS_Decide_Where3	The variable defines if the farmer husband decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
227	PCS_Decide_Where4	The variable defines if the farmer daughter decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
228	PCS_Decide_Where5	The variable defines if the farmer son decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
229	PCS_Decide_Where6	The variable defines if the farmer grandmother decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
230	PCS_Decide_Where7	The variable defines if the farmer grandfather decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
231	PCS_Decide_Where8	The variable defines if the farmer father decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
232	PCS_Decide_Where9	The variable defines if the farmer mother decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
233	PCS_Decide_Where10	The variable defines if the household head decides where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
234	PCS_Decide_Where11	The variable defines if other people decide where to plant the trees: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
235	PCS_Decide_Where_Other	Additional information about who decides where to plant the trees in case it correspond to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
236	Past_Planting	The variable defines if during the last 12 months additional tree seedlings were purchased: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
237	Past_Planting_Spp	Tree species purchased during the last 12 months	NA	text	255	NA	n	y
238	Past_Planting_Num	Total number of tree seedlings purchased during the last 12 months	NA	numeric	3	[1, 500]	n	y
239	Future_Planting	The variable defines if the planting of additional tree seedlings (outside of the project activities) is planned during the next 12 months: 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
240	Future_Planting_No	Explanation in case of negative response. The informatio was transcribed as stated by the farmer	NA	text	255	NA	n	y
241	Future_Planting_Num	Total number of tree seedlings planned to be added in the next 12 months	NA	numeric	4	[1, 1000]	n	y
242	Future_Planting_Spp	Tree species purchased during the last 12 months	NA	text	255	NA	n	y
243	Future_Seedling_Source1	The variable defines if the seedlings will be purchased: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
244	Future_Seedling_Source2	The variable defines if the seedlings will be given free of charge: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
245	Future_Seedling_Source3	The variable defines if the seedlings will be provided by own nursery: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
246	Future_Seedling_Source4	The variable defines if the seedlings will derive from other source: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
247	Seedling_Source_Other	Additional information about the seedling source in case it corresponds to other. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
248	Future_Method1	The variable defines if the farmer plans to use his own method for planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
249	Future_Method2	The variable defines if the farmer plans to dig small planting hole: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
250	Future_Method3	The variable defines if the farmer plans to dig big planting hole: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
251	Future_Method4	The variable defines if the farmer plans to apply manure: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
252	Future_Method5	The variable defines if the farmer plans to apply mulch: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
253	Future_Method6	The variable defines if the farmer plans to apply inorganic fertilizers: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
254	Future_Method7	The variable defines if the farmer plans to water the seedlings: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
255	Future_Method8	The variable defines if the farmer plans to fence the seedlings: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
256	Future_Method9	The variable defines if the farmer plans to shade the seedlings: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
257	Future_Method_Other	Additional information about the farmer own method. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
258	Prev_Trees	The variable defines if the farmer planted any trees with the project in the first round of tree planting (Nov- Dec 2016): 1 = yes; 0 = no	NA	numeric	1	0 | 1	y	n
259	Produce	The variable defines if the trees have entered production: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
260	Produce_Type	Tree products. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
261	Produce_Use	Use of tree products. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
262	GPS_PC_Latitude	Latitude of Plant Comparizon (PC) plot, according to EPSG4326 coordinate system. The data was automatically collected by the device utilized for the survey	NA	numeric	255	NA	n	y
263	GPS_PC_Longitude	Longitude of Plant Comparizon (PC) plot, according to EPSG4326 coordinate system. The data was automatically collected by the device utilized for the survey	NA	numeric	255	NA	n	y
264	GPS_PC_Altitude	Altitude of Plant Comparizon (PC) plot. The data was automatically collected by the device utilized for the survey	m.a.s.l	numeric	255	NA	n	y
265	GPS_PC_Accuracy	Precision of the geographical data of Plant Comparizon (PC) plot. The data was automatically collected by the device utilized for the survey	NA	numeric	255	NA	n	y
266	Num_Trees	Total number of trees inside the PC plot	NA	numeric	2	[0, 42]	y	n
267	County	County of the survey	NA	text	255	Kitui | Machakos | Makueni	n	y
268	Sb_County	Sub-county of the survey	NA	text	255	Kibwezi East | Kitui Rural | Masinga | Mbooni East | Mwala | Mwingi Central | Yatta	n	y

269	Ward	Ward of the survey	NA	text	255	Ekalakala | Ikatini | Invingoni/Nzambani | Kalawa | Kanyangi | Makutano/Mwala | Masongaleni | Matuu | Mtito Andei | Ndalani | Waita	n	y
270	Loc	Location of the survey	NA	text	255	Ekalakala | Endui | Ikaatini | Kalawa | Kalulini | Kanyangi | Katangini | Kathekani | Kathulimbi | Katulye | Kivingoni | Kyawango | Matuu | Mtito Andei | Mutembuku | Mwala | Ndalani | Ndauni | Ngwata | Nthogoni | Nzambani | Syotuvali | Waita	n	y
271	Sb_Loc	Sub-location of the survey	NA	text	255	Endui | Ikaatini | Ititu | Kakumini | Kaluluini | Kanyangi | Kathekani | Kathongo | Kathulumbi | Katitika | Katulani | Katulye | Kibau | Kivandini | Kivingoni | Kyawango | Lower Mukaange | Mandongoi | Mang'Elete | Masimba | Matuu | Mutembuku | Muthingini | Mutomo | Myanyani | Ngomoni | Ngulini | Nyaanyaa | Nzambani | Nzeveni | Syomakanda | Syomunyu | Syotuvali | Thonoa | Waita | Yatta	n	y
272	Village	Village of the survey	NA	text	255	Athi | Chambiti | Changamwe B | Ikatini | Ikongeni | Ilondu | Isaani | Itangini | Itulani | Kaliluni | Kalulini | Kambili | Kamunyuni | Kanduu | Kaseve | Katanga | Kathangathini | Kathiani | Katithi | Katothya | Katulye | Kaunguni | Kavete | Kavumbuni | Kavuthu | Kiambani | Kikule | Kilango | Kiliku | Kimutwa | Kithetheesyo | Kithiani | Kitie | Kitoto | Kitumbini | Kitwamikeu | Kiuanzukini | Komboyoo | Kwa Kutu | Kwandula | Kyanganga | Kyangi | Kyuasini | Kyulu | Likoni | Makutano B | Malumani | Mangetheni | Maongoa | Masimba A | Matiliku | Mbemba Imwe | Mbetwani | Mbusyani | Miambani | Mikameni | Mililuni | Mutkya | Mutomo | Muumbuni | Muunguu | Mwaani | Mwangeni | Mwitasyano A | Ndindi | Ndivu | Ndulumoni | Ngolomoto | Ngomano | Ngomeni | Nguumo | Nzalani | Nzambani | Sombe | Syongungi | Syotuvali | Ulaani | Yimuage | Yumbuni	n	y
273	Tree_Species	Scientific name of the tree species	NA	text	255	Azadirachta_indica | Calliandra calothyrsus | Carica_papaya | Mangifera_indica | Melia_volkensii | Moringa_oleifera | Senna_siamea	n	y
274	Nursery	Nursery of origin of the trees	NA	text	256	NA	n	y
275	Niche	The variable defines the planting location inside the farm, choosing between: Ex_Boundary = external boundary; In_Boundary = internal boundary; Scattered = scattered in cropland; Woodlot; Home_Compound; Along_Terraces; Other	NA	text	255	Ex_Boundary | In_Boundary | Scattered | Woodlot | Home_Compound | Along_Terraces | Other	n	y
276	Other_Niche	The variable provide additional information about the planting location, in case it corresponds to other	NA	text	255	NA	n	y
277	Planting_Date	Date of the planting	YYYYMMDD	date	255	NA	n	y
278	Planting_Hole	The variable defines the type of planting hole used	NA	text	255	Small_Hole | Big_Hole | Other	n	y
279	Other_Planting_Hole	The variable defines the diameter of the planting hole, in case the type correspond to other	cm	numeric	3	[0, 121.1]	n	y
280	Manure	The variable defines if farmyard manure was applied to the tree during the six months after the planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
281	Manure_Freq	Number of manure application since the planting	NA	numeric	3	[0, 108]	n	y
282	Manure_Quantity	Total amount of manure for each application	kg	numeric	4	[0, 18]	n	y
283	Manure_Estimate	The variable defines the method used to estimate the application amount: 1 = using a 90 kgs bag; 2 = using a debe; 3 = using measuring scale; 4 = using kasuku; 5 = others; 6 = using handful(s); 7 = using a wheelbarrow; 8 =bottle top; 9 = pinches; 10 = using a spade	NA	numeric	2	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10	n	y
284	Mulch	The variable defines if mulch was applied to the tree during the six months after the planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
285	Mulch_Freq	Number of mulch application since the planting	NA	numeric	1	[0, 8]	n	y
286	Mulch_Quantity	Total amount of mulch for each application	kg	numeric	5	[0, 725]	n	y
287	Mulch_Estimate	The variable defines the method used to estimate the application amount: 1 = using a 90 kgs bag; 2 = using a debe; 3 = using measuring scale; 4 = using kasuku; 5 = others; 6 = using handful(s); 7 = using a wheelbarrow; 8 =bottle top; 9 = pinches; 10 = using a spade	NA	numeric	2	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10	n	y
288	Fertilizer	The variable defines if inorganic fertilizer was applied to the tree during the six months after the planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
289	Fertilizer_Freq	Number of inorganic fertilizer application since the planting	NA	numeric	1	[1, 5]	n	y
290	Fertilizer_Quantity	Total amount of inorganic fertilizer for each application	kg	numeric	5	[0.005, 5]	n	y
291	Fertilizer_Estimate	The variable defines the method used to estimate the application amount: 1 = using a 90 kgs bag; 2 = using a debe; 3 = using measuring scale; 4 = using kasuku; 5 = others; 6 = using handful(s); 7 = using a wheelbarrow; 8 =bottle top; 9 = pinches; 10 = using a spade	NA	numeric	2	1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10	n	y
292	Watering	The variable defines if watering was provided the tree during the six months after the planting: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
293	No_Watering_Reason	If the tree was not watered, the variable defines why. The information was transcribed as stated by the farmer	NA	text	255	NA	n	y
294	Watering_Freq	Watering frequency: 1 = daily; 2 = every other day; 3 = weekly; 4 = bi-weekly; 5 = monthly; 6 = other	NA	numeric	1	1 | 2 | 3 | 4 | 5 | 6	n	y
295	Watering_Freq_Other	The variable provide additional information about the watering frequency, in case it corresponds to other. The information were transcribed as stated by the farmer	NA	text	255	NA	n	y
296	Watering_Quantity	Total amount of water for each application	litres	numeric	4	[0, 100]	n	y
297	Fencing	The variable defines if the tree seedling was fenced: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
298	Shade	The variable defines if the tree seedling was shaded from direct sunlight: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
299	Assessment_Date	Date of the assessment of tree conditions	YYYYMMDD	date	255	NA	n	y
300	Survival	The variable defines if the tree was still surving at the time of the assessment: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
301	Height	Height of the tree at the time of the assessment	cm	numeric	255	[1.5, 1008]	n	y
302	Diameter	Diameter at the root collar at the time of the assessment	cm	numeric	255	[0, 160]	n	y
303	No_Survival_Reason1	In case the tree did not survive, the variable defines if it died due to drought: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
304	No_Survival_Reason2	In case the tree did not survive, the variable defines if it died due to poor quality seedling: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
305	No_Survival_Reason3	In case the tree did not survive, the variable defines if it died due to livestock damage: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
306	No_Survival_Reason4	In case the tree did not survive, the variable defines if it died due to pests: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
307	No_Survival_Reason5	In case the tree did not survive, the variable defines if it died due to diseases: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
308	No_Survival_Reason6	In case the tree did not survive, the variable defines if it died due to other reasons: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
309	No_Survival_Reason7	In case the tree did not survive, the variable defines if it died due to too much water: 1 = yes; 0 = no	NA	numeric	1	0 | 1	n	y
310	No_Survival_Reason_Other	The variable provide additional information about the cause of death, in case it corresponds to other. The information were transcribed as stated by the farmer	NA	text	255	NA	n	y
311	Notes	Additional observation about tree survival, diseases, pests, etc.The information were transcribed as stated by the farmer	NA	text	255	NA	n	y

Appendix 3 Tree heights and diameters per species

The tree heights and diameters have been measured manually by the enumerators (Magaju et al, 2019 a/b)
In the following figures, only trees which have been planted in November-December 2016 and November-December 2017 are considered. This period has been chosen as this is the main planting period and in order to compare trees with similar age/ planting date.
The boxplot without outliers are displayed to keep the focus on the most frequent values of heights and diameters (Figure 46, Figure 47, Figure 48, Figure 49)

Tree heights:

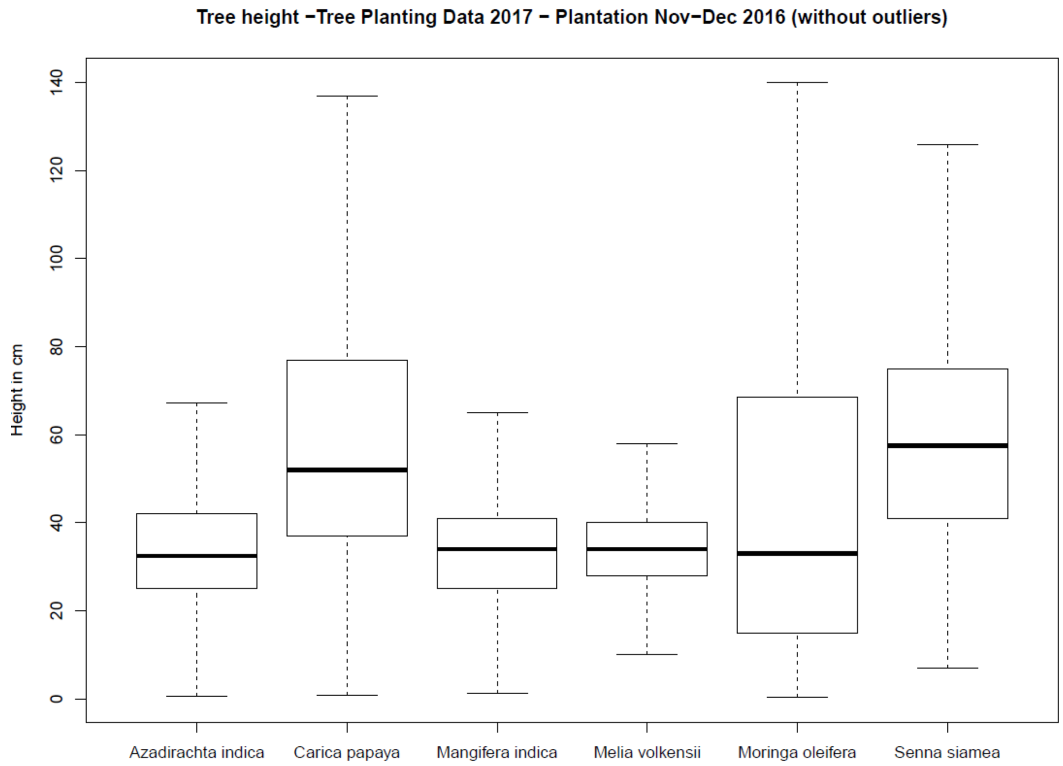

Figure 46: Boxplot tree heights by species - 2017

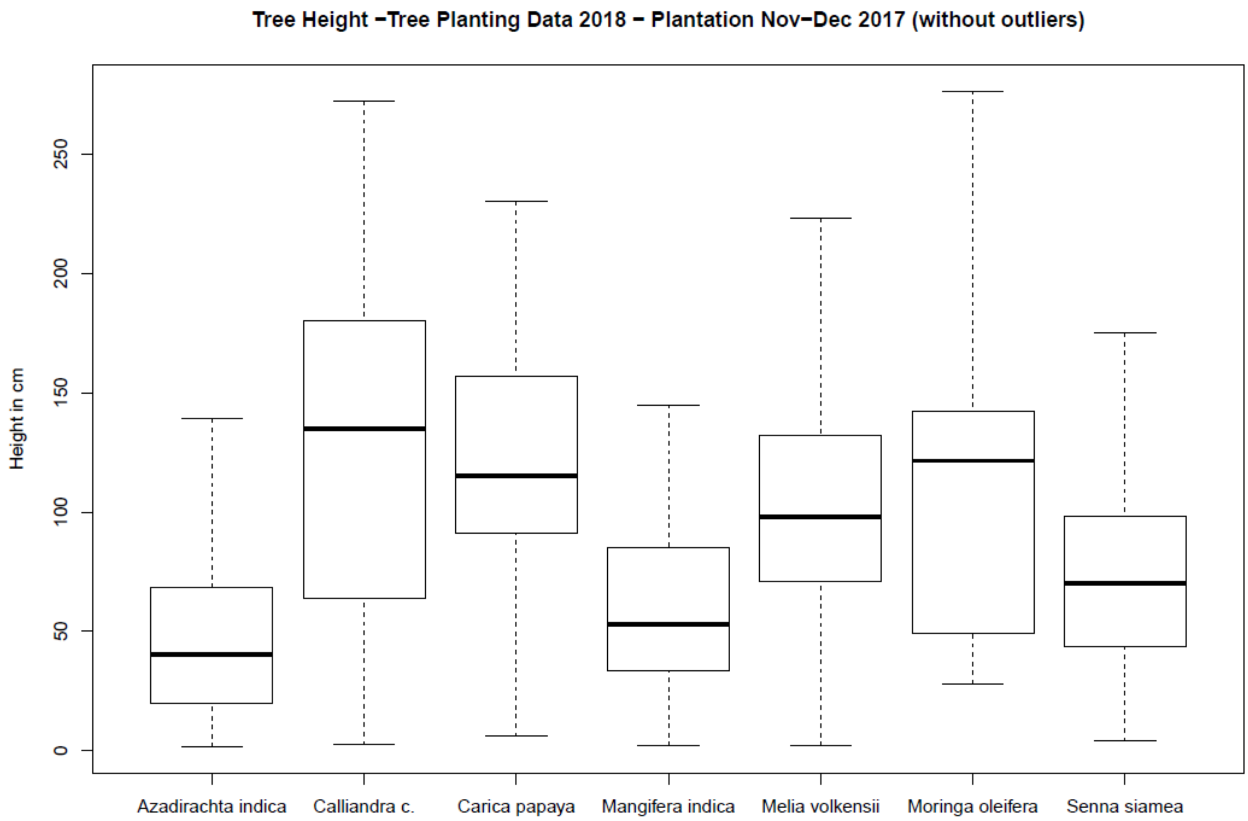

Figure 47: Boxplot tree heights by species - 2018

Tree diameters:

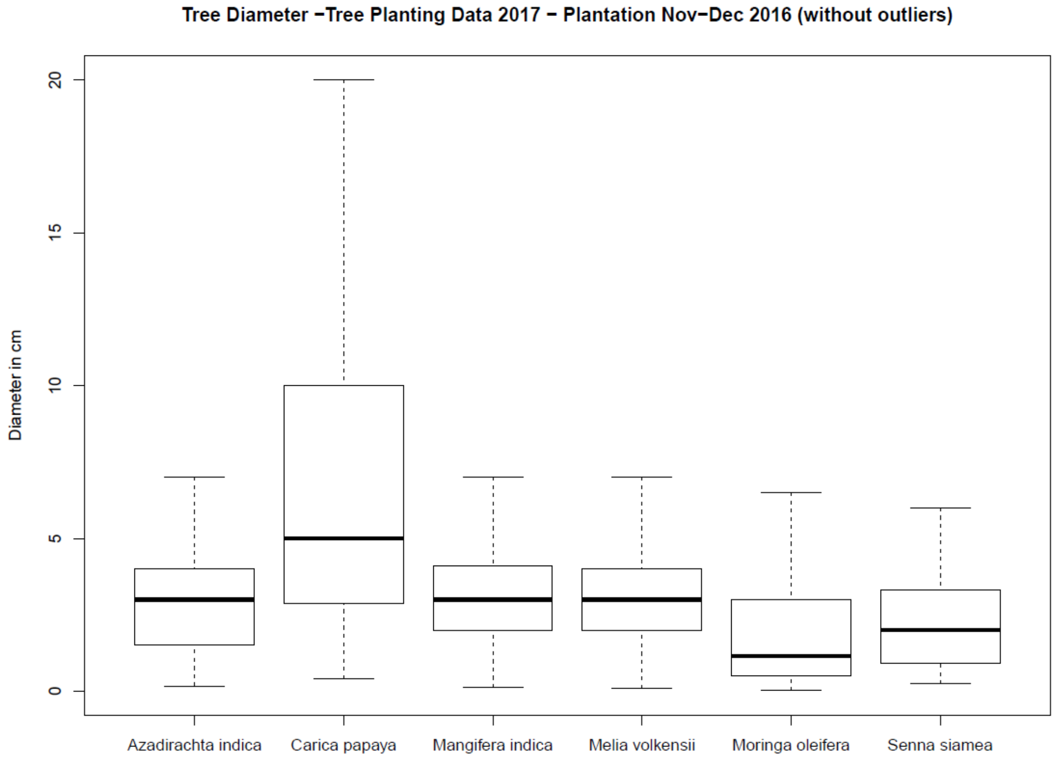

Figure 48: Boxplot tree diameters by species - 2017

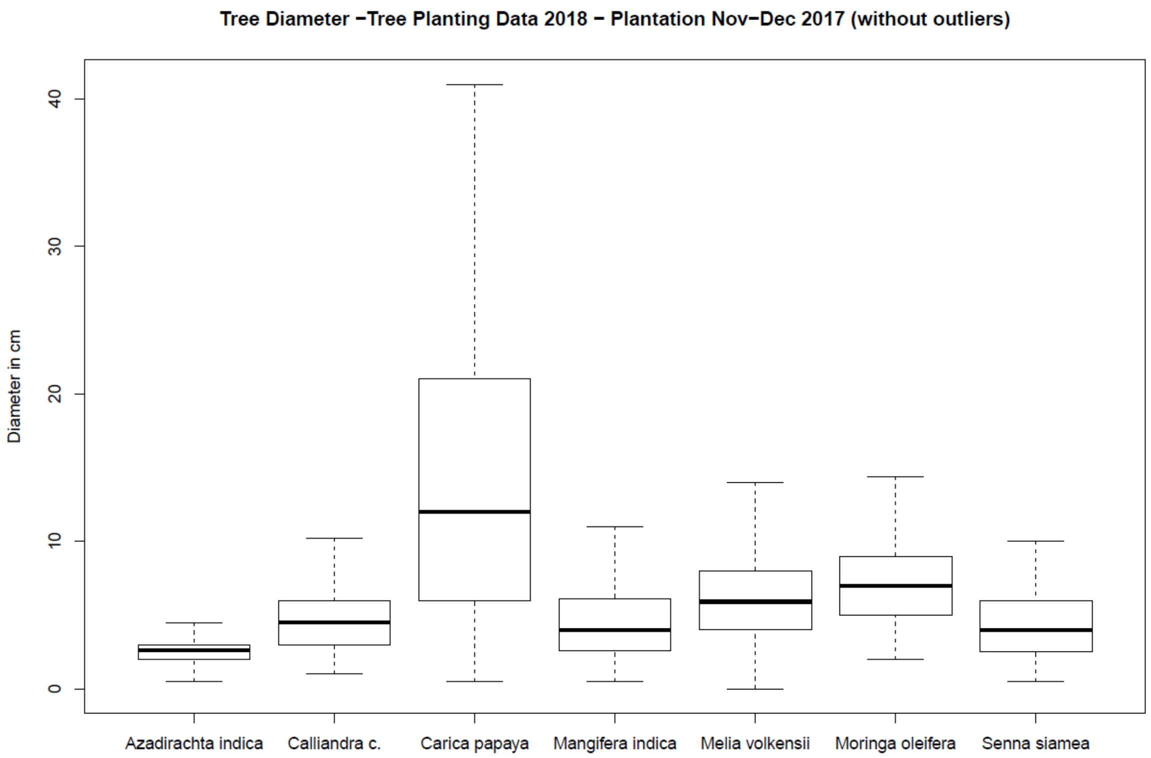

Figure 49: Boxplot tree diameters by species - 2018

These are the data for 'Tree planting data 2017' (Table 16):

Tree planting data 2017

Species	Quantity	Height [cm] Min	1st Quartile	Median	Mean	3rd Quartile	Max
Azadirachta indica	1074	0.5	25	32.5	36.17	42	123
Carica papaya	279	0.79	37	52	60.42	77	450
Mangifera indica	1653	0.78	25	34	35.83	41	180
Melia volkensii	679	2	28	34	36.67	40	190
Moringa oleifera	319	0.27	15	33	48.48	68.5	300
Senna siamea	644	7	41	57.5	60.57	75	187

Species	Quantity	Diameter [cm] Min	1st Quartile	Median	Mean	3rd Quartile	Max
Azadirachta indica	1074	0.17	1.5	3	2.799	4	20
Carica papaya	279	0.41	2.875	5	7.335	10	77
Mangifera indica	1653	0.12	2	3	3.313	4.1	34
Melia volkensii	679	0.1	2	3	3.243	4	36
Moringa oleifera	319	0.02	0.51	1.14	2.649	3	80.4
Senna siamea	644	0.24	0.91	2	2.698	3.3	101

Table 16: Tree heights and diameters per species - 2017

and 'Tree planting data 2018' (Table 17):

Tree planting data 2018

Species	Quantity	Height [cm] Min	1st Quartile	Median	Mean	3rd Quartile	Max	NA's
Azadirachta_indica	953	1,5	20	40,3	49,91	68,3	235	7
Calliandra calothyrsus	153	2,5	64	135	129,1	180	272	
Carica papaya	156	6	91	115	120	157	230	1
Mangifera indica	3046	2	33,7	52,8	58,67	85	1008	11
Melia volkensii	1450	2	71	98	101,4	132	315	9
Moringa oleifera	577	28	49	121,5	114,7	141,5	600	3
Senna siamea	752	4	43,77	70	73,52	98	270	4

Species	Quantity	Diameter [cm] Min	1st Quartile	Median	Mean	3rd Quartile	Max	NA's
Azadirachta_indica	953	0,2	2	2,6	2,723	3	25	7
Calliandra calothyrsus	153	1	3	4,5	5,605	6	160	
Carica papaya	156	0,5	6	12	14,16	21	41	1
Mangifera indica	3046	0,5	2,6	4	4,438	6,1	36,1	11
Melia volkensii	1450	0	4	5,9	5,93	8	142	9
Moringa oleifera	577	2	5	7	7,235	9	42,8	3
Senna siamea	752	0,5	2,5	4	4,473	6	86	4

Table 17: Tree heights and diameters per species - 2018

Then the diameter will be compared to the height for each tree types to get an information about tree growth as per the following graphs (Figure 50, Figure 51).

Outliers are flattening or shortening the main spot locations, some of those outliers will be taken out for better representation:

For the 'Tree planting data 2017', those entries have been taken out for the following representation, (height; diameter) both in cm:

Azadirachta indica: (0,5;20)/ Calliandra Calothyrsus: (450; 14) (268; 54) (1,45;45) (2,18;77)/

Mangifera indica: (27;24) (36;34) (0,78;34)/ Melia volkensii: (37;36)/
Moringa oleifera: (12;80,4) (300;30) (0,35;22) (0,42;23)/ Senna siamea: (71,1;34) (28;101)

For the 'Tree planting data 2018' these are:

Azadirachta indica: (26;25) (2;16) (1,5;16) (1,5;15) (2;14)/ *Calliandra Calothyrsus*: (4,5;160)/
Mangifera indica: (1000;7) (54,2;36,1) (28;25)/ *Melia volkensii*: (123;142) (102;37)/
Senna siamea: (80;86)

'Tree planting data 2017':

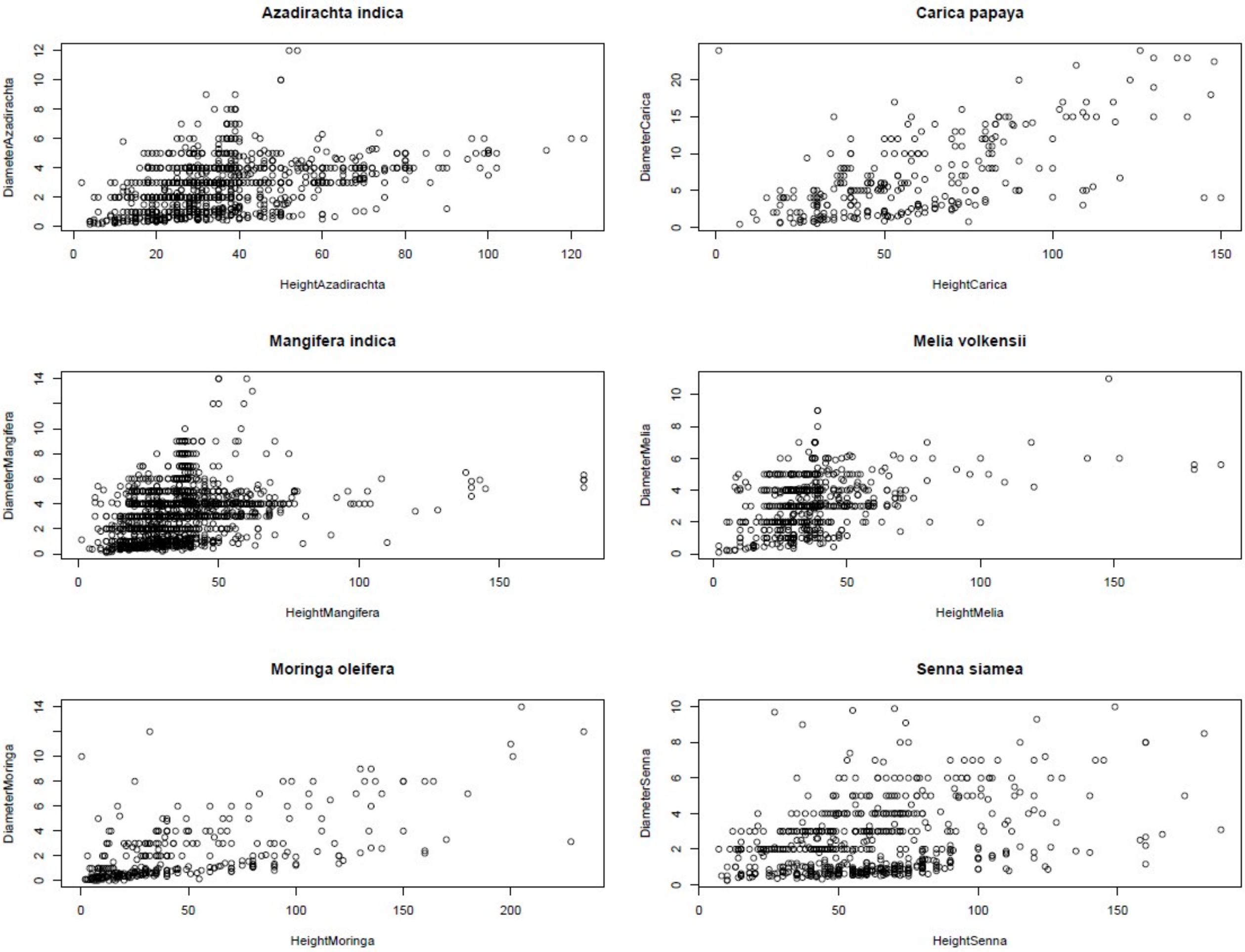

Figure 50: Tree diameter in function of tree height by species - 2017

'Tree planting data 2018':

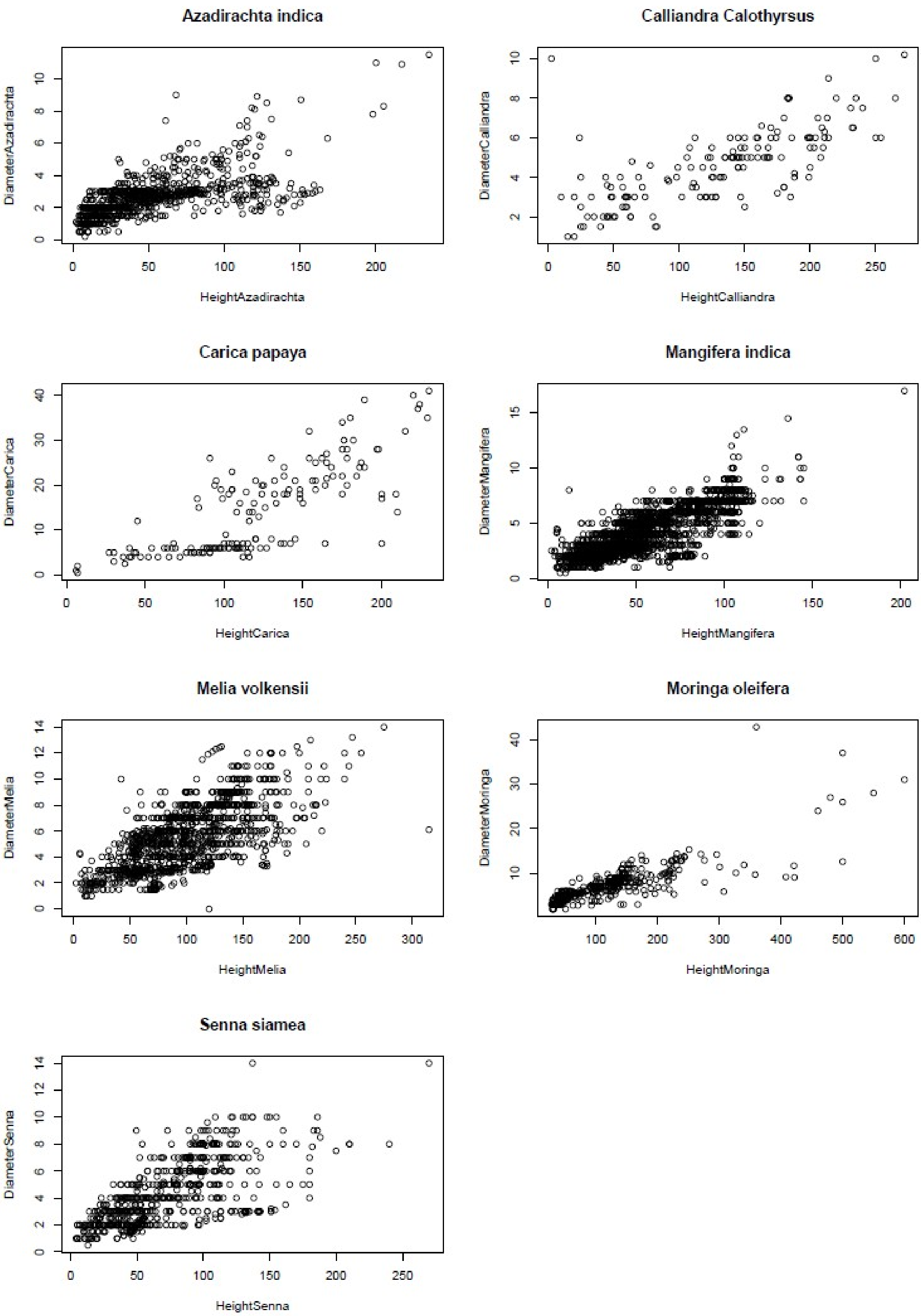

Figure 51: Tree diameter in function of tree height by species - 2018

Appendix 4 Contingency table and biplot Species/ Niches - 2017

Contingency table - Species distribution in the different niches - 2017

Niches \ Species	Azadirachta i.	Carica p.	Mangifera i.	Melia v.	Moringa o.	Senna s.	
Along_Terraces	306	431	1265	317	149	109	2577
Ex_Boundary	170	20	180	324	28	110	832
Home_Compound	1489	351	719	778	370	832	4539
In_Boundary	562	71	436	603	172	314	2158
Other	21	25	86	14	34	45	225
Scattered	520	623	1634	482	431	224	3914
Woodlot	101	53	154	173	36	42	559
	3169	1574	4474	2691	1220	1676	14804

Table 18: Contingency table/ Balloon-plot Species versus Niches – 2017 - all trees

Contingency table - Species distribution in the different niches - only trees that survived - 2017

Niches \ Species	Azadirachta i.	Carica p.	Mangifera i.	Melia v.	Moringa o.	Senna s.	
Along_Terraces	103	79	547	89	56	64	938
Ex_Boundary	67	10	76	69	6	70	298
Home_Compound	599	71	244	233	118	358	1623
In_Boundary	193	10	181	151	43	141	719
Other	12	9	40	4	18	23	106
Scattered	160	126	617	117	91	115	1226
Woodlot	27	26	52	55	15	15	190
	1161	331	1757	718	347	786	5100

Table 19: Contingency table/ Balloon-plot Species versus Niches – 2017 - trees that survived

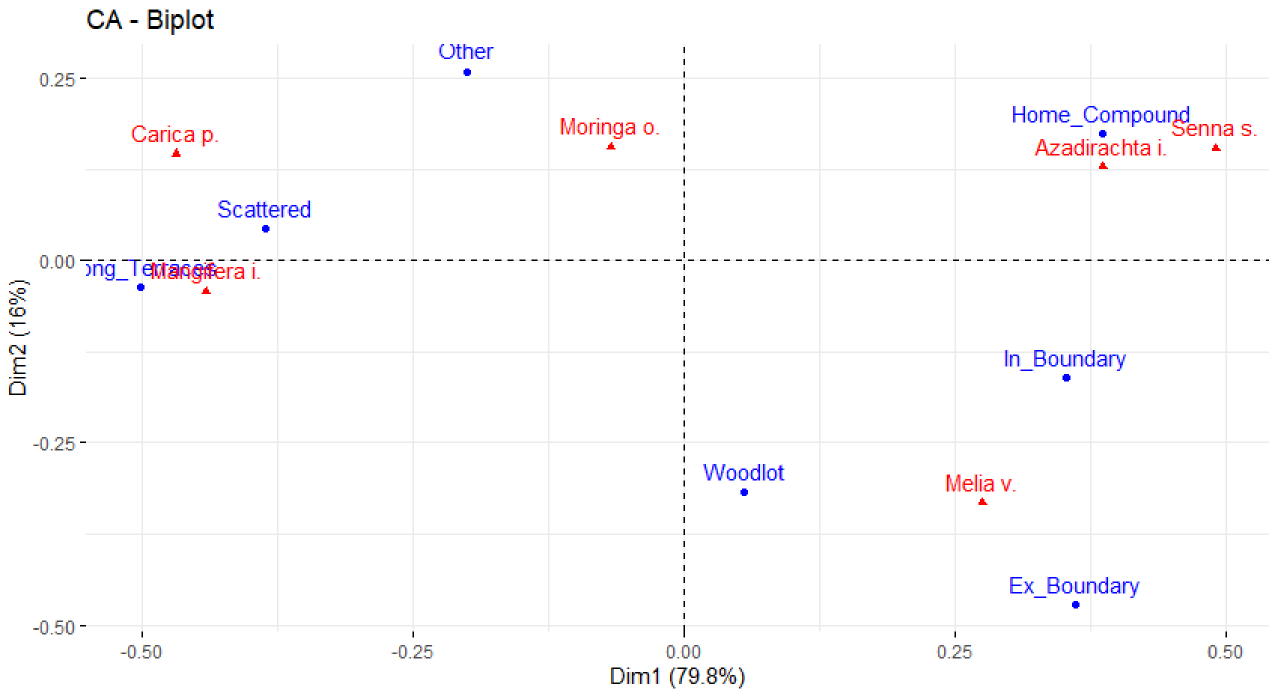

Figure 52: Biplot Correspondence Analysis Species versus Niches - 2017 - all trees

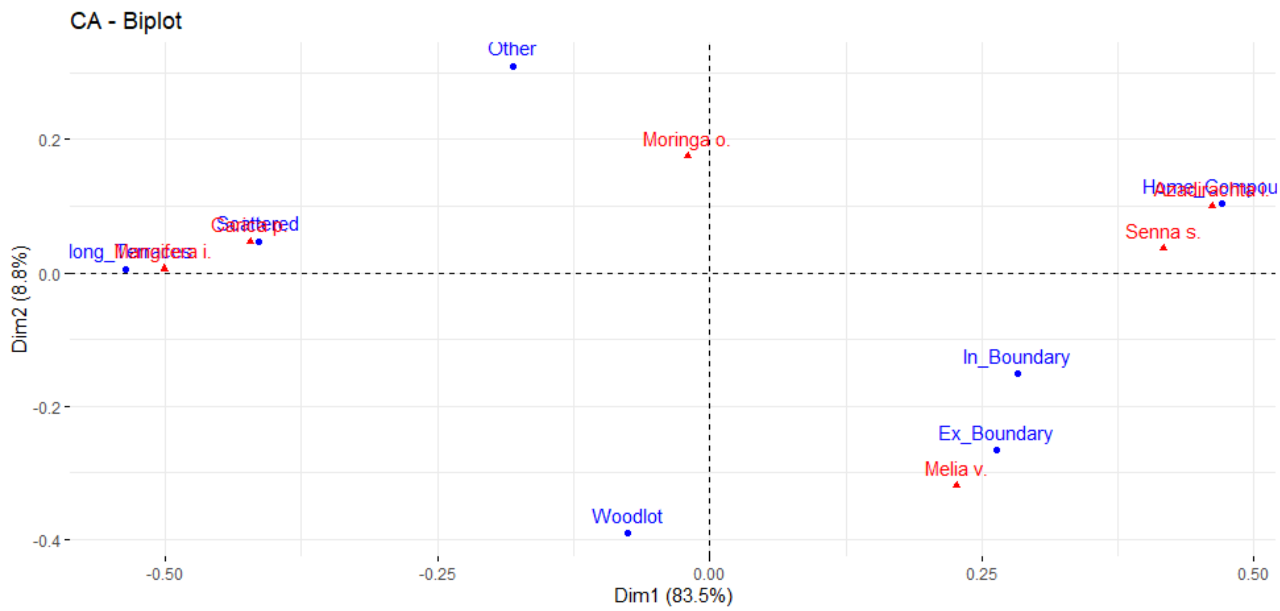

Figure 53: Biplot Correspondence Analysis Species versus Niches - 2017 - trees that survived

Appendix 5 Description of the seven species of the project

The following tree species descriptions are almost completely based from the Agroforestree database from the World Agroforestry Centre cited as Orwa et al. (2009). In case another source is used this is cited explicitly in the description.

Azadirachta indica

English: neem tree, Indian lilac; French: margousier, azadirac de l'Inde; Swahili: mwarubaini, mkilifi

Family: Meliaceae
Native from South Asia and South East Asia, exotic for sub-Saharan African countries although quite widespread.

Description:

- usually evergreen tree, which starts flowering and fruiting at an age of 4-5 years old, but which is economically profitable only after 10-12 years. Lifetime can reach 200 years. Pollination through insects e.g. bees and occurrence of self-incompatibility has been shown. Fruits ripen 12 weeks after flowering
- small to medium size tree, usually up to 15 m tall
- well developed root system
- alternate pinnate leaves, white or pale yellow flowers and 1-2 cm long fruits

Ecology/Climate: tree for lowlands tropics, that can be found in evergreen or dry deciduous forests. The seedlings are sensitive to frost. Adult trees are not resistant to water logging and need light. Rainfall can range from 400-1200 mm per year and temperatures up to 40°C are tolerated.

Soil type: pH 6,2 to 7 and grows on any neutral alkaline soils with a preference for shallow, stony, sandy soils.

Services:

- erosion control: often planted along roads and acts as windbreak, tree can also be used as dune fixation
- drought resistant tree, provide shade
- soil improvement: neem cake (after oil extraction) is used as organic manure and may enhance the efficiency of nitrogen fertilizers by reducing the rate of nitrification and acting as pesticide against nematodes[12], fungi and insects. Leaves and small twigs are used as mulch and green manure. Deep located nutrient can be retrieved by the roots
- Intercropping: with pearl millet

Products:

- medicine: against fungi & parasitic worms; treatment for malaria, hepatitis or periodontal disease, skin treatment: boils, pimples, leprosy; also as antiseptic, diuretic and purgative, etc...
- food: fruits as well as young twigs and flowers, gum from the wounded bark
- tannin or dyestuff
- timber: rough grain and difficult to polish, used for wardrobes, bookcases and closets, construction and fencing from main stem due to its termite resistance
- fuel: good quality charcoal or fire wood
- fodder: leaves although very bitter, birds and bats digest the pulp of the fruits and distribute the seeds.
- seed oils (neem oil) for soaps, cosmetics, pharmaceuticals
- azadirachtin from seeds or leaves used in pesticides, one traditional practice being the 'neem tea' from tree leave to be used as pesticide

12 Roundworms


Figure 54: Neem trees

Source:
www.homeremediess.com


Figure 55: Neem tree flowers

Photo: S. Navie,
Source:
keyserver.lucidcentral.org


Figure 56: Neem fruits and leaves

Photo: K. Sooryan, 2013-06-04
Source:
https://commons.wikimedia.org/

Calliandra calothyrsus

English: red calliandra; French: calliandre; Swahili: mkaliandra

Family: Fabaceae – Mimosoideae
Native from Middle America

Description:

- small leguminous shrub starting giving fruits in the second year and that ripens within 3 months from anthesis.
- tree height 5-6 m, usual trunk diameter of 20 cm
- superficial and deep growing roots
- alternate bi-pinnate leaves 10-19 cm long, green flowers with long purple or red stamens, 8 to 13 cm pods containing black seeds

Ecology/Climate: tree from humid or sub-humid climate with rain that could go from 700 mm to 4000 mm, suitable for moderate altitude up to 1300 m. Mean annual temperature should range from 22 to 28 degrees.

Soil type: slightly acidic soil but not waterlogged or alkaline.

Services:

- erosion control as it easily grows in infertile areas and dominate undesired weeds
- shade and rain protection due to dense foliage
- nitrogen fixing tree through the Rhizobium bacteria and root fungus
- soil improver due to high quantity of green manure generated nevertheless the tannins present in the leaves decrease the microbial breakdown
- ornamental
- hedgerow
- intercropping

Figure 57: Calliandra calothyrsus

Products:

- fodder: leaves and pods
- apiculture: all-year flowers suitable for bee keeping & pleasant bitter sweet honey
- fuel: firewood, charcoal
- fibre: pulp and papermaking

Photo: M.J. Plagens, Kenya, 2017-05
Source: http://www.ngkenya.com/

Carica papaya

English: pawpaw tree, papaya; French: papailler, papayer; Swahili: mpapai

Family: Caricaceae
Native from Costa Rica, Mexico and the US.

Description:

- evergreen "tree-like herb" that is fruiting within 5 months but only live up to 4-5 years. Fruits available all-year round.
- tree height 2-10 m, usual trunk diameter of 10-30 cm
- extensive rooting system
- huge leaves 25-75 cm, tiny yellow flowers, large fruits with orange pulp

Ecology/Climate: tree for warm climate & sunny sites but need to be protected from wind, frost, water logging and floods. Mean annual rainfall requirement is higher and can vary between 1000 mm and 2000 mm and the tolerable altitude range is 0-1600 m

Soil type: fertile loamy soil well drained, pH 6-7

Products:

- food: mainly ripe fruit as breakfast or dessert or green fruit cooked as a vegetable
- medicine: contains carapine that is a heart depressant, amoebicide and diuretic
- latex/rubber: papain from the latex of the green fruit for beverage, food and pharmaceuticals

Figure 58: Carica papaya

Source: https://bangaloreagrico.in/

Mangifera indica

English: Mango; French: Manguier; Swahili: Mwembe, muembe, maembe

Family: Anacardiaceae
Native from the Indian subcontinent. Exotic for sub-Saharan African countries.

Description:

- evergreen tree with irregular flowering that can be waited for up to 10-20 years or more. The flowering takes place at the beginning of the rainy season, and then only small portion leads to fruits that will ripen at the end of the rainy season, 2 to 5 months later. Fruiting is usually occurring every two years. Some trees need cross-pollination (by bats, flies, ants, thrips, bees), some not as flowers can be hermaphrodite[13]. Rain and high humidity are hindering pollination.
- up to 20 m tall, stout trunk of up to 90 cm diameter
- deep roots
- alternate leaves, yellow or green flowers and 8-12 cm long fruits (mangos)

Ecology/Climate: suitable for subtropics with max. elevation of 600 m and protection from frost, and in the tropical zone with max. elevation of 1200 m and a dry period of at least 3 months for fruit production. The optimal temperature range is 24-27°C. The trees are drought and flood resistant.

Soil type: well drained fertile soils pH 5.5 to 7.5 and trees tolerate moderate alkaline soils.

Services:

- provide shade and acts as firebreak
- leaves improve soil fertility while used as mulch
- intercropping with other fruits or vegetable

Products:

- medicine: leaves (warts), seeds, bark
- food: mango fruits rich in Vitamin A and C
- tannin or dyestuff: from bark, yellow-brown for silk tanning
- timber: indoor construction, meat-chopping blocks, furniture, carpentry, flooring,...
- fuel: 4.200 kJ/kg, charcoal and fire wood
- fodder: leaves for cattle in reduced quantities due to danger of death, seeds for cattle or poultry
- apiculture: high quantity of nectar

Figure 59: Mangifera indica leaves

Photo: SierraSunrise, Thailand, 2012-10-04
Source: www.flickr.com

13 Have both male and female reproductive tissues. Retrieved from https://www.merriam-webster.com/dictionary/hermaphrodite

Figure 60: Mango tree

Source: St. Molon,
Burkina Faso, 2018-03-20

Figure 61: Mangifera india flowers

Photo: R. Wendt, Guinea Bissau, 2011-04-17
Source: http://www.westafricanplants.senckenberg.de/

Melia Volkensii

English: Melia; Swahili: Mukau

Family: Meliaceae
Native from Ethiopia, Kenya, Somalia, Tanzania, so **indigenous**.

Description:

- deciduous tree, that starts flowering after 2 or 3 years. Towards the end of the dry season the fruits are ripening while new leaves appear. Leaves, fruits and flowers are produced twice a year and different stages of flowering and fruit maturation can be found on the same branch as the fruit development takes approximately one year.
- tree height from 6 to 20 m, usual trunk diameter of 25 cm
- deep root
- bright green bi-pinnate leaves, small white flagrant flowers and 4 cm green or pale grey drupe-like fruits

Ecology/Climate: tree for drylands, that can be found in combination with *Acacia commiphora*. Rainfall can vary between 300-800 mm per year and the altitude from 350 to 1680 m.

Soil type: sandy, clay and shallow stony with usually good drainage.

Services:

- soil improvement: leave cover in last stage of crop development would increase yields
- intercropping: common nevertheless crops needing a lot of light such as sorghum or millet need good tree management to reduce shade.

Products:

- timber: high quality timber easily to work out.
- fuel: dry branches are gathered for fire wood even there is an annoying smoke, bad charcoal
- fodder: fruits are eaten by giraffe, kudu and goats; farmers believe that the leaves are nutritive for cattle and goats
- apiculture: wood is used to build log hives and flowers are believed to provide high bee forage
- poison: leaf preparation as flee or fly repellents

Source: https://www.betterglobemedia.com/

Figure 62: Melia volkensi seedling plantation in Nyongoro, Kenya

Moringa oleifera

English: Moringa tree, ben-oil tree, cabbage tree, horse-radish tree, benzolive tree; French: Acacia blanc, neverdie, moringa ailé; Swahili: Mronge, mzunge, mlonge, mrongo

Family: Moringaceae
Native from India, Malaysia, Arabic peninsula

Description:

- Small deciduous tree up to 8 m, trunk diameter at breast height about 60 cm. The tree can reach 2,5 m in 1-3 months.
- alternate leaves with opposite pinae, all year sweet smelling white flowers and 15 cm long fruits

Ecology/Climate: invasive species especially on river banks and in high water table savannah. Resistant to drought and frost. The usual conditions are rainfall of at least 500 mm, temperatures from 12,6 to 40°C and altitude from 0-1000 m.

Soil type: well drained clay or clay loam, pH neutral or light acidic.

Services:

- erosion control as wind breaker especially in period of dry spells, can be used as hedge.
- soil improvement: leaves can be used as mulch, the press cake left over of the oil extraction can be used as fertilizer.
- intercropping: provides semi shade for crops sensitive to the sun. Nevertheless Kurauka (2015) mentioned that allelopathy effects of *Moringa Oleifera* has been noticed that could affect the growth of nearby crops, usually due to trees litter.

Products:

- medicine: seeds against skin infection, antibiotic and fungicide, gum is used against asthma, high content of iron in the leaves, oil for prostate and bladder problems, Root and bark for cardiac and circulation problems. The bark is appetizer and digestive.
- food: leaves can be eaten as spinach as there are a source of protein, vitamins A. B and C and minerals such as calcium and iron. Flowers can be used for tea as cold remedy and young pods can be eaten and seeds are used to make oil.
- tanning or dyestuff: blue
- timber: light construction work
- fibre: from the bark to make mat and small ropes
- fuel: can be used for fire wood but bad charcoal
- apiculture: as the tree is flowering almost the whole year, it provides nectar for bees

Figure 63: Moringa oleifera leaves

Source: http://phytocode.net

Senna siamea

English: Kassod tree, yellow cassia, cassia; French: Casse de Siam, bois perdrix, cassia; Swahili: Mjohoro

Family: Fabaceae. Subfamily: Caesalpinioideae
Native from South Asia and South East Asia

Description:
- evergreen tree, flowering and fruiting starts at 2-3 years age throughout the whole year
- medium size up to 18 m tall, straight trunk of up to 30 cm diameter
- deep roots, rootlets in the topsoil 10-20 cm may reach 7 m from the stem in one year and spread up to 15 m
- alternate & pinnate leaves, yellow flowers and 5-25 cm long pods
- the tree is a legume but not a nitrogen fixing tree, nevertheless it forms ectomycorrhiza (symbiotic relationship of the roots with a fungal symbiont)

Ecology/Climate: suitable for low land tropics (elevation not more than 1300 m) as it is sensitive to cold and frost. Suitable for monsoon climate with max dry period of 4-8 months and annual rainfall: 400 mm -2800 mm. Roots need access to groundwater. High light requirements with mean annual temperature 20-31°C.

Soil type: deep well drained fertile soils pH 5.5 to 7.5; also grow on lateritic soils with drainage. Intolerant to saline soils.

Services:
- coppicing tree that can build hedgerows for erosion control increasing water infiltration
- high biomass production (up to 500 kg/year for a well grown tree)
- ornamental

Products:
- medicine: fruit (internal worms), heartwood (laxative)
- food: young fruits, leaves, flowers
- tannin or dyestuff
- timber: hardwood, heartwood: dark brown & sapwood: pale 6 cm
- fuel: 22.400 kJ/kg, charcoal
- fodder: for ruminants only as pig and poultry are sensitive to the highly toxic alkaloids and other plant compounds contained in the leaves, flowers and pods

Figure 64: Senna siamea

Photo: R. v. Blittersdorff, Tanzania, 2008-03-11, Source: www.africanplants.senckenberg.de

Figure 65: Senna siamea flowers

Photo: G. Baumann, Malawi, 2011-11-24
Source: www.africanplants.senckenberg.de

Figure 66: Senna siamea trunk

Photo: R. Biechele, Nigeria, 2006-12-03,
Source: www.africanplants.senckenberg.de

Figure 67: Senna siamea pods

Photo: G. Baumann, Malawi, 2011-05-08
Source: www.africanplants.senckenberg.de