SOCIO-TECHNOLOGICAL FACTORS INFLUENCING SMALLHOLDER FARMERS' ADAPTATION OF AGROFORESTRY TECHNOLOGIES IN THE EASTERN HIGHLANDS OF UGANDA

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DECLARATION

I, **Fred Kalanzi,** declare that this dissertation results from my research. Where the ideas that are not of my own were used, they have been accredited. This dissertation has never been submitted to any university or institution of higher learning for any academic award.

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DEDICATION

I dedicate this dissertation to those I can't mention by name: my ever-loving family, especially my children and a few individuals who have financially supported my cause.

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LIST OF ABBREVIATIONS AND ACRONYMS

NARO	National Agricultural Research Organisation
NaFORRI	National Forestry Resources Research Institute
ICRAF	World Agroforestry Centre
DAAD	German Academic Exchange Service
NGO	Non-Governmental Organisation
CBO	Community Based Organisation
DTPB	Decomposed Theory of Planned Behaviour
TPB	Theory of Planned Behaviour
IDT	Innovation Diffusion Theory
AEZ	Agro-Ecological Zone
SSA	Sub-Saharan Africa
ACIAR	Australian Centre for International Agricultural Research
MMR	Mixed Methods Research
FGD	Focus Group Discussion
KII	Key Informant Interview
SPSS	Statistical Package for the Social Sciences
ASCLOGIT	Alternative Specific Conditional Logit
FAO	Food and Agriculture Organisation of the United Nations
UBOS	Uganda Bureau of Statistics
UNDP	United Nations Development Programme
Mt.	Mountain
UN	United Nations
IFAD	International Fund for Agricultural Development
UNEP	United Nations Environmental Programme
SDGs	Sustainable Development Goals
T4FS	Trees for Food Security

ABSTRACT

Agroforestry has been identified as the most sustainable remedy to counter declining farm productivity, especially in Sub-Saharan Africa. Based on this, state and non-state actors have promoted several agroforestry technologies in Uganda's eastern highlands to improve farm productivity. Using on-farm demonstration trials, agroforestry training sessions and field days, smallholder farmers were expected to make choices on the recommended agroforestry technologies and apply them to their crop fields in a scientifically recommended way for the anticipated outcomes to be realized. However, socio-technological and intrahousehold decision-making shape how smallholder farmers utilize agroforestry technologies because of heterogeneous farm contexts. This study sought to establish the rationale for smallholder farmers' adaption practices of the agroforestry technologies to their contexts in Uganda's eastern highlands. The specific objectives addressed by the empirical chapters in this dissertation were to; (1) determine the influence of socio-technological factors on smallholder farmers' choice of agroforestry technologies for adaptation, (2) examine the influence of intra-household decision-making on the use of agroforestry technologies, and (3) describe the smallholder farmers' modifications and practices in suiting the agroforestry technologies to their contexts. The study used a mixed methods research strategy that employed an exploratory sequential approach to collect the data. Results indicated that the number of tree species desired by the farmer and the perceived value of the technology were the most critical socio-technological factors commonly influencing smallholder farmers' choices of agroforestry technologies. The study also found male decision-makers dominated pre-production, production and post-production agroforestry decisions. The only decision where females' decision-making power was close to their male counterparts was deciding which crops to plant in a particular agroforestry plot.

Furthermore, smallholder farmers made several adjustments to the recommended practices. They devised their practices to make the technologies more applicable to their contexts based on their knowledge, experience, preferences and priorities. The modifications and practices across the agroforestry technologies were mainly intended to enhance tree seedling survival, diversify benefits, optimize space utilization, minimize management costs, and shorten the waiting time for tree-related benefits. Thus, there is a need for a hybrid (knowledge exchange) extension model situated in the agricultural innovation system's thinking to allow smallholder farmers to contribute

to agroforestry technology development. This will help generate economically viable and socially acceptable technologies for smallholder farmers.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Smallholder farmers are increasingly becoming a backbone to agricultural productivity in the face of limited land for agriculture due to increased population pressure. A smallholder farmer's definition varies greatly across countries and regions since their categorization can depend on various factors such as land ownership, farm size index, agricultural activity and production scale, the share of family labour, and access to assets and resources. A generally acceptable definition looks at a smallholder farmer as one with a low asset base and operating on less than 2 ha of land (Khalil et al., 2017; Maass, 2013). Smallholder farmers produce 70-80% of the world's food (FAO, 2014; Maass, 2013), underlying their importance in the global food value chain. However, smallholder farmers are also food insecure, prompting international agencies to orient their development policy (IFAD & UNEP, 2013). For example, goal 2 of the UN sustainable development goals (SDGs) aims to end hunger and achieve food security through sustainable agriculture. The goal's (SDG 2.3) key targets are to double small-scale food producers' agricultural productivity and income by 2030 (UN, 2015). Despite relevant development policies, food insecurity continues to rise among smallholder farmers, especially in Sub-Saharan Africa. Smallholder farmers in Sub-Saharan Africa (SSA) experience declining farm productivity which, among other things, is worsened by widespread land degradation, unsustainable farming technologies, soil erosion, limited knowledge of improved practices and yield losses due to climate change (Sheahan & Barrett, 2014; Sommer et al., 2013). There have been efforts to promote agricultural interventions that are environmentally sound, technically appropriate and socio-economically viable (Pretty, 2008). Agroforestry, increasingly recognized as a cheap and sustainable approach, has become a viable option for smallholder farmers to increase their farm productivity (Weber & Knoke, 2017; Scherr et al., 2012).

According to van Noordwijk et al. (2016), agroforestry is a practice and science of the interface and interactions between agriculture and forestry, involving farmers, crops, livestock and forests/trees at multiple scales. Agroforestry has been suggested as a global solution to increase land productivity while reducing environmental impacts and economic risks for smallholder farmers (Paul et al., 2017). Agroforestry ranks high worldwide among the initiatives for improving farm productivity (Nair & Garrity, 2012). The contribution of agroforestry to farm productivity emerges from two attributes of trees. One is their role in maintaining and restoring the physical environment needed to sustain crop yields (Bukomeko et al., 2018; Kalanzi & Nansereko, 2015). The other is various tree products' role in smallholder farmers' livelihoods (Arnold & Dewees, 2014; Luedeling et al., 2016). Some scholars refer to agroforestry as an ancient practice since smallholder farmers have been integrating trees in their cropping systems for different reasons, including fuelwood, fruits, medicine and shade (Gram et al., 2017; Lamond et al. 2016). But global efforts in research and development in the past three decades have transformed it into a science-based integrated approach capable of addressing many of the world's most land-management severe challenges. It's estimated that nearly a billion hectares of agricultural landscapes already have more than 10% tree cover and an estimated total of 1.6 billion hectares of land worldwide has the potential to be under agroforestry in the foreseeable future (Nair & Garrity, 2012). For example, in Ethiopian highlands, agroforestry technologies recommended by scientists were found to maximize farm productivity and smallholder farmers' incomes (Kassie, 2016).

1.2 Policy and institutional framework supporting agroforestry in Uganda

There is currently no comprehensive policy and institutional framework that focuses explicitly on the development and promotion of agroforestry in Uganda. Because agroforestry has a strong interconnectedness with forestry and agriculture, several agricultural and forestry-related policies and institutional frameworks try to address agroforestry issues in a disaggregated as opposed to an integral manner. The Uganda Forest Policy provides for on-farm forestry by advocating for tree-growing on farms (agroforestry) in all farming systems and innovative mechanisms to deliver forestry extension and advisory services. The National Forestry and Tree Planting Act aims to guide and cause Uganda's people to plant trees. The National Forestry Plan aims at increasing on-farm production of various forest products such as poles, firewood, fruits, timber, tree seeds and planting materials and aromatic oils. The National Forestry and Tree Planting Regulations, 2015 provides for ownership of planted trees on the farm. The Agriculture Sector Strategic Plan 2015/16-2019/20 seeks to accelerate production and productivity at the national and household level by focusing on generating and upscaling sound agricultural research and climate change resilient technologies across the priority and strategic commodities. Forestry policies focus on protecting the forestry resource, but they provide a disincentive for farmers to grow the trees in the protection process. On the other hand, the agricultural policies centre on increasing productivity without much emphasis on agroforestry. Such policy constraints have affected the promotion of agroforestry technologies among smallholder farmers.

Other national frameworks also have provisions that emphasize issues of interest to agroforestry. Uganda's vision 2040 highlights the need to restore degraded lands through tree planting on private land as one of the means to restore forest and tree cover from the current 15% to 24%. The National Development Plan III, among other things, focuses on protecting and restoring degraded fragile ecosystems, increasing national forest cover and economic productivity of forests, integrating environmental sustainability and climate change policy interventions in all sector development plans. All these efforts demonstrate that the Ugandan government generally supports agroforestry but the mosaic nature in which agroforestry elements spread over several policies and institutional frameworks constrains agroforestry development in Uganda. For instance, agroforestry is not mainstreamed in the agricultural extension services, yet the national forestry resources research institute conducts agroforestry research under the agriculture ministry. Agroforestry continuously ranks low on the list of local government priorities in terms of budget allocation. This has left an agroforestry implementation gap in the main agricultural extension services. Therefore, the past two decades have seen non-governmental organisations such as ICRAF, World Vision and Vi Agroforestry involved in agroforestry research and development.

1.2.1 Agroforestry promotion in Uganda

It has long been a tradition of smallholder farmers to integrate trees into their agricultural landscapes. While not abandoning the original patterns, the emphasis of the researchers and development practitioners in the recent decades has been on agroforestry as a science-based discipline. Many agroforestry interventions have been implemented in various parts of Uganda with support from research and development agencies. The World Agroforestry Centre (ICRAF) and the National Agricultural Research Organisation (NARO) through the National Forestry Resources Research Institute (NaFORRI) have spearheaded agroforestry research in Uganda. Scientists have extensively researched and introduced agroforestry technologies to smallholder farmers to ensure a widescale uptake to realise benefits at a landscape scale. In this study's context, an agroforestry technology as adapted from Von Carlowitz (1989) is an intervention that specifies the function, locations, arrangements and management of tree species and associated crop or livestock components on the farm for enhancing productivity. In the technology promoter's interest, such specifications must be followed for the agroforestry technology to deliver the anticipated outcomes to the smallholder farmers.

The promising research findings for agroforestry to address smallholder farmer challenges has prompted the government, international organisations, NGOs and CBOs to extend these technologies to smallholder farmers. Some of the promising technologies that have been extended to farmers include fodder banks, intercropping, fruit orchards, woodlots, boundary planting, riverbank protection, trees for soil and water conservation, improved fallows and tree seed stands. Although such technologies are highly relevant to smallholder farmers, they have received mixed reactions and consequently, their utilization has not been as fast as desired (Kiyingi et al., 2016; Mfitumukiza et al., 2017; Mwase et al., 2015).

1.3 The concept of technology adaptation

Once agroforestry was aligned in the scientific domain, it was anticipated that agroforestry technologies would be implemented in a scientifically proven way to deliver the outcomes expected. However, even when they have been proven to work, new technologies are hardly perfect upon introduction into smallholder farmers' contexts. Similarly, smallholder farmers' efforts to apply technologies often reveal eventualities that were not apparent before the introduction. The situation is even supposed to be more pronounced for agroforestry technologies that require a more complex management regime than pure agricultural or forestry undertaking to achieve optimum benefits (Nair, 1993). The decline in the use of agroforestry technologies is anticipated due to their composition and management complexity (Buck et al., 1999; Scherr, 1991). These eventualities require shaping and re-shaping the agroforestry technologies to suit smallholder farmers' socio-economic, cultural and biophysical contexts (Tambo & Wünscher, 2017). This interplay in which the technology is conditioned by the local context (socio-economic, biophysical and cultural aspects) is called adaptation.

Technology adaptation is the process of adjusting the original design of the technology to fit the circumstances different from where it was initially developed (Agrawal & Perrin, 2008). The smallholder farmers sometimes change the original technology design, indicating that it's not aligned with their existing conditions. In this study's context, by the 'adaptation of agroforestry technology', I refer to the adjustment of the technical prescriptions of an agroforestry technology as reflected in the choices, utilization and modifications and practices to make it applicable to smallholder farmers' local contexts. In a heterogeneous smallholder farmers' context, adaptation begins with choosing among alternative agroforestry technologies (Lahiri et al., 2018). Technology utilisation comprises the decision-making process embedded in the farming household's socio-technological context (Cedamon et al., 2018; Nelson et al., 2007). The operating efficiency ultimately achieved with a chosen technology depends on the users' modifications undertaken during the utilization process. As smallholder farmers utilise the new technology, they may discover its ramifications in response to their needs and interests. This may necessitate them to modify the technology and apply it to their situation. Smallholder farmers' modifications are often done in a given technology's recommended practices and do not significantly change its original configuration. However, such modifications may result in varied outcomes from those intended during the technology's original design (Nelson et al., 2007). Modifications may incentivize other farmers to use the technology when the results are appropriate to the smallholder farmer, enhancing its scaling-out.

1.3.1 Context of agroforestry technology adaptation in the eastern highlands of Uganda

Widespread deforestation and increasingly intensive land use to sustain a growing population have increased soil erosion, lowered soil fertility, and reduced agricultural productivity in Uganda's eastern highlands. Frequent mudslides, landslides, and climate change exacerbate the situation (Bauw et al., 2016). The prevailing situation has prompted state and non-state agencies to promote agroforestry among smallholder farmers in the region. Among the ongoing projects in the area, an agroforestry project titled "Trees for Food Security (T4FS) " has been implemented by ICRAF since 2014 in partnership with NARO, World Vision Uganda, Makerere University and the district local governments in Mbale, Manafwa, Bududa and Namisindwa districts. Under the project, a range of scientifically proven agroforestry technologies (e.g. fodder-bank, woodlot, intercropping, fruit orchards and boundary planting) believed to work under smallholder farmer conditions were introduced and promoted. However, surveys in the area highlighted the most popular ones as boundary planting, intercropping, and woodlot (Kabiru et al., 2017; Okia et al., 2016). On-farm trials were used to collect data on the performance of the preferred tree species on different sites and spur smallholder farmers' uptake by identifying the appropriate tree species that suited different contexts and their recommended practices, especially spacing and planting pattern (Roo et al., 2019). The technologies experimented in on-farm trials mainly worked well in similar agro-ecologies (Barrios & Coe, 2014; Mowo et al., 2014). On-farm trials complemented agroforestry training sessions and field days to help smallholder farmers choose the appropriate agroforestry technologies that suited their contexts (Muthuri et al., 2017). Smallholder farmers could identify the appropriate tree species that suited different contexts, their recommended spacing and planting pattern. But because smallholder farmers also needed guidance on management options (pruning and thinning), the already established on-farm trials, where applicable, served as demonstration plots to showcase how pruning and thinning could be done. In instances where the trials did not have the trees' right age to demonstrate tree management (pruning and thinning), the already established trees on farmer fields were used. Hence 'on-farm demonstration trials' as applied in this study refer to on-farm trials and demonstration plots/trees on farmer fields that demonstrated technology-specific recommended practices (spacing, planting pattern, pruning and thinning) to smallholder farmers. For smallholder farmers to realise maximum benefits, recommendations provided by scientists needed to be followed in what may be looked at as 'blueprint instructions' in extension. Blueprints assume homogeneity among smallholder farmers in social and economic terms, which is not the case. Adaptation of the technology is oriented towards its merit, value or worth as shaped by the users' socio-economic and biophysical aspects than by any scientific principle.

1.4 Problem statement

The National Agricultural Research Organisation (NARO), ICARF and the district local governments have extensively promoted agroforestry technologies in Uganda's eastern highlands. Using approaches such as on-farm demonstration trials, agroforestry training sessions, and field days, much information and support have been given to smallholder farmers in the region to integrate appropriate agroforestry technologies into their existing cropping systems. Although follow-up shows that agroforestry technologies have increased to about 60%, smallholder farmers have made different choices and modified agroforestry technologies contrary to how they were advised by the experts (Mwangi & Muthuri, 2016). Why this is so is not clearly explained. There are concerns that the intended outcome of increasing farm productivity using promoted agroforestry technologies will not be realized if smallholder farmers continue implementing in their way contrary to what was recommended by the experts. If the ways smallholder farmers are utilizing the agroforestry technologies do not deliver on the anticipated outcome of farm productivity, it may consequently result in negative feedback. Other potential users (smallholder farmers) who are being targeted may refuse to take up agroforestry technologies on their farmlands due to early users' negative experiences, which they may not know is attached to their wrong choices and modifications.

Several factors influence smallholder farmers' choices and modifications for short-term technologies such as new crop varieties. First, the socio-technological context of the smallholder embedded in aspects such as the perceived value, ease of use, compatibility, subjective norms, perceived behavioural control could influence farmer choice and modifications of technologies (Ronner et al., 2018; Zeweld al., 2017). Second, the intra-household decisions moderated by decision-making relations between male and female decision-makers over critical farming activities can influence how a smallholder family uses new technologies (David, 1998; Ssebaggala et al., 2017; Bertocchi et al., 2014; Anderson et al., 2017). However, for long-term technologies such as agroforestry, which is knowledge and capital intensive (Ndamani & Watanabe, 2015), limited information exists to explain smallholder farmers' rationale for their choices and modifications of agroforestry technologies, especially as conditioned by the socio-technological factors and intra-household decision-making. Understanding smallholder farmers' motivation for making specific choices and modifications is critical in tuning agroforestry interventions to suit specific targets and increasing their relevance in improving farm productivity.

1.5 Objectives

The overall objective of this study was to establish the rationale for smallholder farmers' choices and utilization and the modifications and practices to adapt agroforestry technologies to their contexts in Uganda's eastern highlands. The specific objectives addressed by the empirical chapters in this dissertation were to;

i. Determine the influence of socio-technological factors on smallholder farmers' choice of agroforestry technologies for adaptation
ii. Examine the influence of intra-household decision-making on the use of agroforestry technologies
iii. Describe the smallholder farmers' modifications and practices in utilizing the agroforestry technologies for improved farm productivity

1.6 Justification of the study

Globally, agroforestry has become a topical issue in sustaining the productivity of smallholder farms. The Ugandan agricultural sector is characterized by poor smallholder farmers who cannot meet the high fertilizers and labour costs to increase farm productivity. While smallholder agriculture's contribution to the national economy is indisputable, support for smallholder farmers in Uganda remains wanting (Busingye, 2017). Agroforestry has been one of the approaches amenable to smallholder farming because it's cheap and sustainable. Several agroforestry technologies have been promoted to enable farmers to choose those that increase productivity in their contexts. However, in cases where smallholder farmers make inappropriate choices, adverse outcomes can result, which may be costly for a long-term enterprise like agroforestry. This study examined how smallholder farmers' socio-technological context blends experts' recommendations of agroforestry technology. This is necessary to improve the relevance and impact of agroforestry technologies and prepare agricultural agencies for their scaling-up. This study contributes to capturing important intra-household decision-making aspects, often neglected in the design and promotion of agroforestry technologies among smallholder farming households.

The concept of gender, though not the subject of this study, recognizes that the principal adult male and female decision-makers hold different positions and have additional responsibilities and decision-making power within the household. Harmonizing their needs and interests could be more complicated in agroforestry, where trees as long-term enterprises offer a wide range of benefits. Unfortunately, decision-making relations between male and female decision-makers in agroforestry remain generally unexplained. This study attempted to distil how decision-making power influences the use of agroforestry technologies from a more localized context of a smallholder farming household.

Smallholder farmers' utilisation of new agroforestry technologies lies at the intersection between technical knowledge and indigenous knowledge. Smallholder farmers' modifications of agroforestry technologies serve as a pointer to their often-underrated innovative capacity. This study, which unearths smallholder farmers' modification, could help strengthen the argument that development agencies need to engage well with smallholder farmers to generate agroforestry solutions that work in their contexts.

1.7 Conceptual and theoretical frameworks of the study

Agroforestry technologies in the eastern highlands of Uganda were mainly promoted to improve smallholder farm productivity and ultimately enhance food security. The assumption was that smallholder farmers would apply the technologies according to the recommendations offered by the experts as demonstrated using on-farm trials. The agroforestry technologies were promoted as a basket of options from which smallholder farmers were supposed to select what specifically suited their contexts. Since new technologies are never perfect, they require adaptation to fit into the smallholder farming household's biophysical, socio-economic and cultural contexts. In the context of this study, the agroforestry technological choices, use and modification and practices characterise the adaptation process informed by the smallholder farmers' psychological factors and intra-household dynamics moderated by the demographic characteristics (Figure 1).

In the context of this study, agroforestry technologies were promoted through trainings and a network of on-farm demonstration trials. This allowed smallholder farmers to interact with the promoted new technologies (boundary planting, intercropping and woodlot) and discover their ramifications. During the interaction of the social (human) and the promoted agroforestry technologies (here referred to as socio-technological context), smallholder farmers' evaluation of the technologies was constructed and (re)shaped. Socio-technological factors emerge that inform smallholder farmers' choice decisions among agroforestry technologies. The perceived value, ease of use, and compatibility constitute smallholder farmers' evaluation of the technologies. Besides, other factors are embedded in other people's influence and smallholder farmers' evaluation of their abilities to implement their choices.

Therefore, the conceptual framework (Figure 1) investigated how socio-technological factors influenced smallholder farmers' choice of agroforestry technologies (objective 1, chapter 2 of this study) and employed the Decomposed Theory of Planned Behavior (DTPB) (Taylor & Todd, 1995) as a framework. The DTPB draws from the Theory of Planned Behaviour (TPB) (Ajzen, 1985) and the Innovation Diffusion Theory (IDT) (Rogers, 1983) to generate tenets that are relevant to this study. The DTPB postulates that outcome actions in a given context are influenced by attitude, subjective norms and perceived behavioural control (Taylor & Todd, 1995). The theory decomposes attitude tenet as applied in the TPB into perceived value, ease of use and compatibility. This study translates into a person's perception of agroforestry technology regarding value attached to the technology, ease of use, and compatibility with the smallholder farmer's existing practices and needs. Subjective norms refer to the social influence the smallholder farmers experience from those they interact with in the community, leading them to choose a particular agroforestry technology. Perceived behavioural control refers to the smallholder farmer's ability to possess the necessary resources and opportunities to use a given agroforestry technology as conditioned by knowledge and skills, prerequisite resources, and belief in their ability.

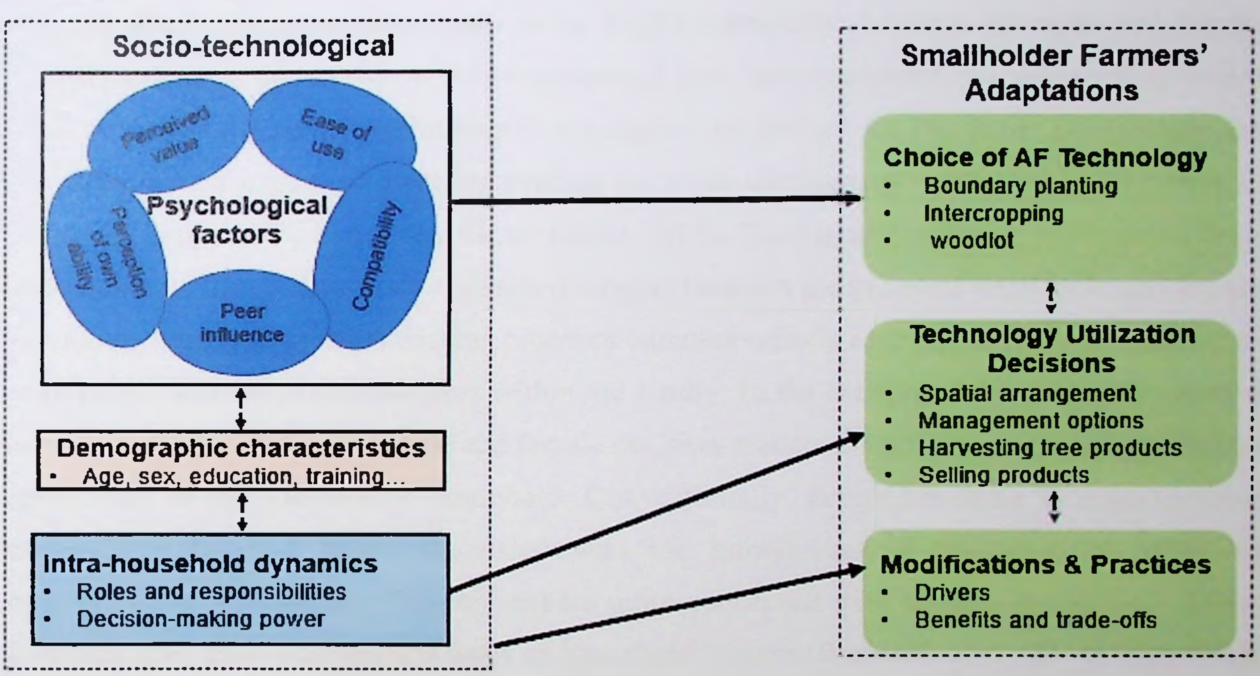

Figure 1.1: Conceptual framework of the study (Source: own elaboration).

Technology utilization at the household level is a function of intra-household dynamics interpreted as roles and responsibilities and decision-making power. Earlier studies applied a unitary model, which assumes that a household is a single production or consumption unit (for a critique of this point of view, see Becker, 1965). However, it later emerged that outcomes of the household decisions are affected by the allocation of resources and the power relations within the household (Anderson et al., 2016). The effect is even more pronounced in dual-headed households, households with two principal decision-markers (husband and wife) where decisions result from the bargaining process. There could be other external influences, but in dual-headed households, the decision-making responsibilities rest upon the husband and wife (referred to as male and female decision-makers in the context of this study). In most SSA, where men seem to assume the responsibility of household heads because of social norms and institutions, daily negotiations among decision-makers must occur to achieve household productivity.

When agroforestry technologies are presented to the dual-headed smallholder household, intra-household dynamics will influence the type and application of the chosen agroforestry technology and the accrued benefits in the household (Anderson et al., 2016). In a quest for multiple objectives within the family, including income and food security, allocating the meagre resources such as land and labour to agroforestry tends to be highly contestable between the male and female decision-makers in the family. It is conceptualized that intra-household decision-making would influence how agroforestry technologies are applied or utilised on the farm. To examine the influence of intra-household decision-making on using agroforestry technologies (objective 2, chapter 3), I applied the bargaining theory (Stahl, 1972). The bargaining theory posits that a dual-headed household's decisions are negotiated directly between the principal adult male and female decision-makers. The decision-making process's outcome reflects each decision-maker's ability to claim power upon individual choices within the family. In the context of this study, the relative decision-making power of the male and female decision-makers informs the decisions reached on agroforestry in the dual-headed household. Conventionally, decision-making in a dual-headed household is believed to be associated with the intra-household allocation of roles and responsibilities, with female decision-makers more concerned with home consumption. At the same time, their male counterparts focus on household income (Bertocchi et al., 2014). This divide in roles and responsibilities can raise conflict of interest during the implementation of agroforestry. If each decision-maker selfishly acts to pursue decisions that favour their roles and responsibilities, conflicts arise that may affect the agroforestry outcome(Anderson et al., 2016). Therefore, understanding the intra-household decision-making can serve as a springboard to ensure that agroforestry's anticipated outcomes benefit both male and female decision-makers.

This study also sought to characterise smallholder farmers' modifications in the utilisation of agroforestry technologies (Objective 3, chapter 4). The modifications and practices would suit agroforestry technologies to the smallholder farmers' biophysical, socio-economic and cultural context. In this study, it's hypothesized that while the nature of modifications (adjustments and changes) smallholder farmers are making on the recommended practices of an agroforestry technology (objective 3) may intend to make the technology more complaint to their needs, such modifications may also result into trade-offs in attaining farm productivity.

1.8 Overview of the research methodology

This section provides the overall research approach highlighting the study area, research design and data (sources, collection and analysis). However, each empirical chapter offers specific details on the respective research methods and data analysis practices.

1.8.1 Study area selection

The study was conducted in Uganda's eastern highlands due to the history of decline in productivity of once very fertile and productive volcanic soils. The eastern highlands of Uganda are characterized by steep slopes where a high rate of environmental degradation emerging from population pressure has increased the occurrence of soil erosion, floods, mudslides, landslides as well as pests and diseases to crops and animals; and it's believed that agroforestry can help to abate some of these challenges (Graham et al., 2021). Because of these challenges, the agro-ecological zone has been a focus of agroforestry interventions from state and non-state agencies that are trying to demonstrate the importance of trees in the farming landscape for enhancing and sustaining crop productivity (Buyinza et al., 2019; Gram et al., 2018; Rahn et al., 2018). Agriculture is characterized by small-scale subsistence farming, which largely depends on human labour and simple hand tools like hoes and machetes, although ox-ploughing is done in a few cases. The impoverished population heavily relies on natural resources for the provision of energy and construction materials. Manafwa and Namisindwa districts were purposively selected as study sites because of their extended and excellent interface of communities with different actors (government and non-government) that promoted agroforestry interventions and a reportedly receptive community in embracing agroforestry technology (Barrios and Coe 2014). The two districts are located on the slopes of Mt. Elgon and are densely populated. Previously large farms have been subdivided into small landholdings along patrilineal inheritance. The districts also form part of the Trees for Food Security (T4FS) project sites – an Australian Centre for International Agricultural Research (ACIAR) funded project to improve household food security and smallholder livelihoods through widespread adoption of appropriate agroforestry technologies.

The area receives a bimodal rainfall pattern with average annual rainfall and a temperature of 1500 mm and 23^{0}C, respectively. The peak rains occur in April-May and September-November, occasionally characterized by landslides (Broeckx et al., 2019). The soils are classified as inorganic clays of high plasticity (Mugagga et al., 2012). The local communities live between 1000 m.a.s.l. at the foothill and 2200 m.a.s.l. close to the protected Mt. Elgon National Park – a major ecosystem shared by all the region's districts. The eastern highlands of Uganda has the country's highest population density of 900 persons per square kilometre, with a population growth rate of 3.4 percent per annum (UBOS, 2016). Due to the high population density of approximately 250-300 persons per km^2 (Gram et al., 2018), the landscape mainly consists of intensively managed smallholder farms with subsistence agriculture and livestock farming as the main occupations. Land productivity is reportedly lower than its potential due to soil erosion, poor land management practices and climate change (Gebru., 2019).

1.8.2 Research design

A Mixed Methods Research (MMR) strategy employing qualitative and quantitative procedures was used in this study (Creswell, 2014; Schoonenboom & Johnson, 2017). Combining qualitative and quantitative approaches was necessary to better understand the smallholder farmers' adaptations of agroforestry technologies. MMR designs are primarily classified based on timing in three ways: concurrent, sequential or multiphase combinations (Schoonenboom & Johnson, 2017; Tashakkori & Teddlie, 2010; Walker & Baxter, 2019). This study employed the exploratory sequential approach (Almalki, 2016), in which data was collected in three phases (Figure 3). Phase one involved collecting qualitative data using key informant interviews and focus group discussions, enriching the variables to be investigated in the quantitative phase. Phase 2 involved cross-sectional surveys in collecting quantitative data to answer objectives 1 and 2. Phase 3 was based on a case study design to collect qualitative data for characterizing smallholder farmers' modifications during the implementation of agroforestry technologies. The selection of the cases was informed by phase two of the study.

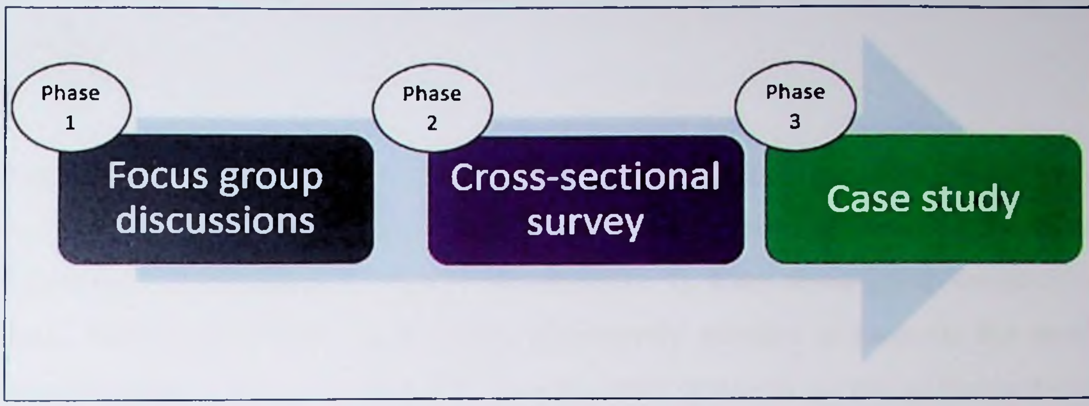

Figure 1.2: Phases of data collection

1.8.3 Study population and sampling procedure

The study targeted smallholder farming households in the study area that had benefited from agroforestry interventions. Both probability and non-probability sampling practices were used to select study respondents. The study populations differed for objectives 1 and 2, which involved a cross-sectional survey. Still, the sampling frames were obtained with the help of sub-county extension workers and Community Development Officers. To collect data for objective 1, a list of 1,011 households engaged in agroforestry was generated as the sampling frame. The household head or spouse was interviewed because they were assumed to be more knowledgeable about agroforestry. If any was not available, the household was dropped from the survey. For objective 2, the study population consisted of 495 dual-headed households implementing agroforestry. In each dual-headed household, both husband and wife were interviewed separately for questions related to intra-household decision-making. For each of objectives 1 and 2, the total size of the sampling frame was used to generate following Krejcie and Morgan (1970) formula below:

$$n = \left(\frac{pqZ^2_{1-\alpha/2}}{d^2}\right) \times DF$$

Where: p = is the prevalence, q=1-p, d = precision (5%), Z1- α/2 = desired level of confidence, α = 0.05 (1.96) and DF = Design effect.

Since n /N > 0.05, the correction factor is applied;

$$n_f = \frac{n}{1 + \left(\frac{n}{N}\right)}$$

Nonprobability sampling was used to obtain participants for the focus group discussions and select cases for objective 3. Data from the cross-sectional survey was complemented by seven focus group discussions (3 for objective 1 and 4 for objective 2). Each focus group consisted of 9-12 participants. Twelve households (cases) were purposively selected to examine the smallholder farmer modifications. These were selected from the cross-sectional survey participants based on their in-depth knowledge and experience about the respective agroforestry technologies.

1.8.4 Data collection methods and tools

Various methods and tools were used to collect data for this study, including semi-structured interviews, Key Informant Interview (KII), Focus Group Discussions (FGDs), and in-depth interviews. Appropriate methods are selected for each of the objectives as described below.

Focus group discussions

A focus Group Discussion (FGD) is defined as "a group of people informally 'interviewed' in a discussion setting (Edgeley, Stasiewicz, & Hammond, 2020; Ghazali, 2014). The FGD is a useful method in exploring and examining peoples' opinions and experiences about a given phenomenon, topic or issue (Carlsen & Glenton, 2011; Ghazali, 2014). The FGDs were conducted with agroforestry farmers that were purposively selected. The size of the FGD ranged from 9 to 12 participants, with an average of about 9 participants. This number of participants is considered optimal for holding meaningful discussions (Carlsen & Glenton, 2011; Rabiee, 2004).

Furthermore, this number of FGD participants was large enough to obtain various perspectives in the time available. On average, it took up to 2 hours to get information on smallholder farmers' opinions in each focus group discussion. To capture data from the FGDs, a written guide was developed for each objective (Appendix 3) to facilitate and guide the discussions. The discussions were held in a conversation style where the researcher acted as the moderator and adopted a probing approach to clarify issues and help participants attain a consensus.

Survey

This study applied a cross-sectional survey to collect standardized quantitative data for objectives 1 and 2. Semi-structured questionnaires, with both open-ended and close-ended questions, were used in both cases (Appendix 4). A questionnaire was developed and pre-tested before actual data collection for each objective. The purpose of pre-testing the tool was to check for the questions' consistency, sequence, and flow. The pilot testing also aimed to establish the duration of each interview for better planning. The information generated from the pilot testing was used to refine the questionnaires before the actual surveys. Adjustments were made for clarity and sequencing of questions. The pilot study was part of an intensive training organized for research assistants involved in data collection.

Key Informant Interviews

Key Informant Interviews (KIIs) are face-to-face, in-depth interviews aiming to get a deeper understanding of a given phenomenon by allowing for the free flow of ideas and information (Kumar, 1989; Lavrakas, 2008). Key informants were purposively selected based on their role, knowledge and experiences in promoting agroforestry in the study area. The trees for food security project reports obtained information about the key informants' roles and knowledge. Face-to-face interviews were conducted with key informants that included the project coordinator of the T4FS project, representatives of the district departments of agriculture, forestry and environment (Manafwa and Namisindwa districts), sub-county extension workers and community development officers for Butta and Namabya sub-counties, and selected community leaders in the two sub-counties. These interactive sessions were guided by a KII guide to elicit information on agroforestry technologies coverage, the approaches used in the promotion, critical areas of implementation and the implementing households. The key informant guide used is appended (Appendix 2).

In-depth interviews

In-depth interviews involve conducting intensive individual interviews with a few respondents to explore their perspectives on a particular situation (Boyce & Neale, 2006). Based on a case study approach, 12 cases were selected purposively based on age (young: 18 – 35 and old: above 35 years) and sex (male or female) for in-depth interviews to examine smallholder farmers' modifications and practices used to make agroforestry technologies more applicable to their contexts. The selection followed a stratified purposive procedure in which the three agroforestry technologies (boundary planting, intercropping and woodlot) formed the strata (under each stratum, 4 cases were selected). An in-depth interview checklist (Appendix 6) was used to elicit data from the cases. With consent from each case, an audio recorder was used to keep a natural flow of the conversation and ensure that all the interview details were captured (Rutakumwa et al., 2020).

Field observations

Farm observations are critical in helping the researcher validate a phenomenon in a natural setting (Smily, 2015). Photographs are a vital source of evidence in case study research (Yin, 2018). Direct observations were done to prove the modifications and practices, understand their actual uses, and ascertain the adjacent crops' condition, suggesting their implications on-farm productivity. Photographs were taken to capture evidence of some of the critical elements of smallholder farmers' modifications and practices.

1.9 Data analysis

Where an audio recorder was used, data were transcribed verbatim. Analysis of information from focus group discussions and in-depth interviews was proceeded by data reduction based on structural codes linked to the research questions addressed in the study. The reduced data collected from in-depth interviews and field observations were subjected to inductive content analysis (Pandey, 2018) based on keywords-in-context to generate themes. Some of the respondent's direct quotes from FGDs were used to further interpret and qualify the quantitative analysis outputs. Qualitative data from in-depth interviews were later presented as themes, anecdotal or descriptive statements.

Quantitative data were analyzed using both SPSS version 20 and STATA version 14.0. The quantitative data interpretation largely depended on the emerging patterns observed from the various statistical analyses and content analysis responses from qualitative data. Percentages and means were used to summarise the smallholder farmers' profiles and agroforestry technologies. The t-test static and chi-square were used to analyze the relationship between continuous and discrete variables. The t-test provided the probability that the difference between the two means was caused by chance.

nalysis of variance (ANOVA) F-test of differences in means (F-value) was used to compare the neans of a given continuous variable across agroforestry technologies. If a significant F-test was ound at a less than 0.05 level of significance, Tukey's post hoc test at 95% family-wise confidence evel was performed to determine those means significantly different from each other.

actor analysis was used to generate the indices for the latent variables used in the model. The aiser-Mayor-Oklin measures of sampling adequacy (KMO) and Bartlett's Test of Sphericity hich relates to the validity and suitability of responses was used at a threshold of >0.5 and ≤0.05, espectively, to check for suitability of data for factor analysis (Field, 2009). To find out the nulticollinearity between independent variables, collinearity diagnostic tests were done using the 'ariance Inflation Factor (VIF) values (at a threshold of VIF ≤ 5.00). During model validation, ollinear variables were dropped to avoid getting biased estimates emanating from nulticollinearity. An Alternative Specific Conditional Logit (ASCLOGIT) model was estimated determine the socio-technological factors influencing farmers' choices of agroforestry echnologies. This was undertaken by normalizing the most preferred alternative as the base ategory (Greene, 2012; Mcfadden, 1974). Marginal effects were used to determine how much the robability of choosing a given agroforestry technology changes for a unit change in predictor ariable or a change from 0 to 1 in the case of discrete variables.

or each agroforestry decision, average decision-making power scores were obtained for both usband and wife. An independent t-test was used to determine whether mean accord scores for ach agroforestry decision significantly differed between male and female decision-makers. Iultiple linear regression was used to determine the socio-demographic factors influencing emales' decision-making power. The model is specified as:

$$F_p = \beta_0 + \beta_1 h_1 + \beta_2 h_2 + \ldots + \beta_n h_n + \varepsilon$$

Vhere:

- F_p = Overall decision-making power of female decision-maker
- β_0 = Coefficient of the constant term (intercept)
- $h_1, h_2, \ldots, h_n$ = Socio-demographic factors of the female decision-maker
- $\beta_1, \beta_2 \ldots \beta_n$ = regression coefficients; ε = random error

1.10 Organization of the dissertation

This dissertation is written in a manuscript format with five chapters. The first chapter provides the general introduction and context of the study. It also presents the study's overall framing concerning the knowledge gap, research objectives, conceptual framework, and overview of its methodology. The empirical chapters (Chapter 2 to Chapter 4), to a great extent, stand independent but are interconnected through cross-references. Each chapter addresses a specific objective and begins by providing the specific background to the topic, also drawing on related literature. It then elaborates the methodology, explains the results and offers clear conclusions and recommendations.

Chapter 2 focuses on determining the influence of socio-technological factors on smallholder farmers' choices of agroforestry technologies for adaptation. The chapter describes the predominant agroforestry technologies in the study area. It also highlights how farmers' socio-technological context determines their choices of agroforestry technologies. Chapter 3 examines the influence of intra-household decision-making on the use of agroforestry technologies. The chapter characterizes the agroforestry farming households, describes the roles and responsibilities of male and female decision-makers in agroforestry and highlights the agroforestry decisions made within a dual-headed household. It examines and compares the decision-making power of male and female decision-makers and its implications on implementing agroforestry technologies at the household level and highlights the factors that influence females' decision-making power. Chapter 4 unveils smallholder farmers' modifications in adapting agroforestry technologies to suit their local contexts. It characterizes the modifications and assesses their pros and cons in attaining increased farm productivity. This empirical chapter concludes by suggesting a more holistic approach that promotes technologies and engages smallholder farmers in developing appropriate technologies that suit their production context. Finally, Chapter 5 summarises all the chapters and presents the general discussion emphasizing how the chapters are connected and the overall study objective.

References

Agrawal, A., & Perrin, N. (2008). *Climate adaptation, local institutions and rural livelihoods: IFRO Working Paper # W081-6*. Retrieved from http://www.umich.edu/~ifri/Publications/W08I6%20Arun%20Agrawal%20and%20Nicolas%20Perrin.pdf.

Almalki, S. (2016). Integrating Quantitative and Qualitative Data in Mixed Methods Research—Challenges and Benefits. *Journal of Education and Learning*, *5*(3), 288. https://doi.org/10.5539/jel.v5n3p288

Anderson, C. L., Reynolds, T. W., & Gugerty, M. K. (2016). Husband and Wife Perspectives on Farm Household Decision-making Authority and Evidence on Intra-household Accord in Rural Tanzania. *World Development*, *90*, 169–183.

Anderson, C. L., Reynolds, T. W., & Gugerty, K. M. (2017). Husband and Wife Perspectives on Farm Household Decision-making Authority and Evidence on Intra-household Accord in Rural Tanzania. *World Development*, *90*, 169–183.

Arnold, J. E. M., & Dewees, P. A. (2014). *Farms Trees and Farmers*: Routledge. https://doi.org/10.4324/9781315071107

Barrios, E., & Coe, R. [Richard] (2014). *Participatory trials design workshop report*. Mbale, Uganda. Retrieved from World Agroforestry Centre (ICRAF) Uganda website: http://www.worldagroforestry.org/sites/default/files/participatory%20Trials%20Design%20workshop-Rwanda%202013.pdf

Bauw, P. de, van Asten, P. [P.], Jassogne, L. [L.], & Merckx, R. (2016). Soil fertility gradients and production constraints for coffee and banana on volcanic mountain slopes in the East African Rift: A case study of Mt. Elgon. *Agriculture, Ecosystems & Environment*, *231*, 166–175. https://doi.org/10.1016/j.agee.2016.06.036

Becker, G.S. (1965). A theory of the allocation of time. The Economic Journal 75: 493–517.

Bertocchi, G., Brunetti, M., & Torricelli, C. (2014). Who holds the purse strings within the household? The determinants of intra-family decision making. *Journal of Economic Behavior and Organisation*, *101*, 65–86.

Boyce, C., & Neale, P. (2006). Conducting in-depth interviews: A guide for designing and conducting in-depth interviews for evaluation input (Pathfinder International Tools Series). Retrieved from Pathfinder International website: http://www2.pathfinder.org/site/DocServer/m_e_tool_series_indepth_interviews.pdf.

Broeckx, J., Maertens, M., Isabirye, M., Vanmaercke, M., Namazzi, B., Deckers, J., . . . Poesen, J. (2019). Landslide susceptibility and mobilization rates in the Mount Elgon region, Uganda. *Landslides*, *16*(3), 571–584. https://doi.org/10.1007/s10346-018-1085-y

Buck, L. E., Lassoie, J. P., & Fernandes, E. C. M. (1999). *Agroforestry in sustainable agricultural systems. Advances in agroecology*. Boca Raton, Fl., London: CRC Press.

Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.458.9810&rep=rep1&type=pdf#page=201

Bukomeko, H., Jassogne, L. [Laurence], Kagezi, G. H., Mukasa, D., & Vaast, P. (2018). Influence of shaded systems on Xylosandrus compactus infestation in Robusta coffee along a rainfall gradient in Uganda. *Agricultural and Forest Entomology*, *20*(3), 327–333. https://doi.org/10.1111/afe.12265

Busingye, J. D. (2017). Smallholder farming and food sovereignty in Uganda: An in-depth analysis of policy vis-a-vis farmers' realities. *Net Journal of Agricultural Science*, *5*(4), 131–140. https://doi.org/10.30918/NJAS.54.17.038

Buyinza, J. [J.], Muthuri, C. W., Downey, A., Njoroge, J., Denton, M. D., & Nuberg, I. K. (2019). Contrasting water use patterns of two important agroforestry tree species in the Mt Elgon region of Uganda. *Australian Forestry*, *82*(sup1), 57–65. https://doi.org/10.1080/00049158.2018.1547944

Carlsen, B., & Glenton, C. (2011). What about N? A methodological study of sample-size reporting in focus group studies. *BMC Medical Research Methodology*, *11*, 26. https://doi.org/10.1186/1471-2288-11-26

Cedamon, E., Nuberg, I., Pandit, B. H., & Shrestha, K. K. (2018). Adaptation factors and futures of agroforestry systems in Nepal. *Agroforestry Systems*, *92*(5), 1437–1453. https://doi.org/10.1007/s10457-017-0090-9

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks: SAGE Publications.

Edgeley, C. M., Stasiewicz, A. M., & Hammond, D. H. (2020). Prioritizing Research Needs in Natural Resources: Using Q-Methodology as a Focus Group Discussion Tool. *Journal of Forestry*, 1–7. https://doi.org/10.1093/jofore/fvaa035

FAO (2014). *The state of food and agriculture. Innovation in family farming: Vol. 2014*. Rome. Retrieved from http://www.fao.org/3/a-i4040e.pdf

Gebru, B. M., Wang, S. W., Kim, S. J., & Lee, W.-K. (2019). Socio-Ecological Niche and Factors Affecting Agroforestry Practice Adoption in Different Agroecologies of Southern Tigray, Ethiopia. *Sustainability*, *11*(13), 3729. https://doi.org/10.3390/su11133729

Ghazali, F. A. (2014). A critical overview of designing and conducting focus group interviews in applied linguistics research. *American Journal of Educational Research*, *2*(1), 6–12. Retrieved from http://article.scieducationalresearch.com/pdf/education-2-1-2.pdf

Gram, G., Vaast, P., van der Wolf, J., & Jassogne, L. [Laurence] (2018). Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in Mount Elgon, Uganda. *Agroforestry Systems*, *92*(6), 1625–1638. https://doi.org/10.1007/s10457-017-0111-8

Gram, G., Vaast, P., Wolf, J., & Jassogne, L. [Laurence] (2017). Local tr... knowledge ca... track agroforestry recommendations for coffee smallholders along a cli... mate gradient in Mount Elgon, Uganda. *Agroforestry Systems*, 1–14.

Greene, W. H. (2012). *Econometric analysis* (7th ed.). Boston: Prentice Hall.

IFAD, & UNEP (2013). *Smallholders, food security and the environment*. Rome. ...e.

Kabiru, S. [Saratu], Hassan, S. [Salem], Umar, U., & Musab, I. (2018). An Inventory of Agroforestry Practices in Butta Sub-County, Manafwa District, Uganda. *Asian Journal of Environment & Ecology*, *5*(4), 1–7. https://doi.org/10.9734/AJEE/2017/39518

...lanzi, F., & Nansereko, S. (2015). Exploration of farmers' tree species selection for coffee ...groforestry in Bukomansimbi district of Uganda. *International Journal of Research on Land- ...e Sustainability*, *1*, 9–17.

...G. W. (2016). Agroforestry and land productivity: Evidence from rural Ethiopia. *Cogent ...& Agriculture*, *2*(1), 99–116. https://doi.org/10.1080/23311932.2016.1259140

...A., Conforti, P., Ergin, I., & Gennari, P. (2017). *Defining smallscale food producers to ...arget 2.3 of the 2030 agenda for sustainable development* (Working paper series No. ...). Rome. Retrieved from Food and Agriculture Organisation of the United Nations ...://www.fao.org/3/a-i6858e.pdf.

..., A., Phiri, M., Buyinza, M., & Agaba, H. [H.] (2016). Adoption of On-Farm ...stry by Smallholder Farmers in Uganda. *Journal of Sustainable Development*, ...

...gan, D. W. (1970). Determing sample size for research activities. ...*chological Measurement*, *30*, 607–610.

...*cting key informant interviews in developing countries* (pp. 1-40). ...*for International Development*. Washington DC. Retrieved from ...Development website: ...tem/files/content/resource/files/main/conducting-key-informant-

...Z. (2018). Technology adoption, adaptation and growth ...483.

..., A., & Sinclair, F. L. (2016). Local knowledge of tree ...on on coffee farms. *Exploratory Agriculture*, 1–15.

...*dia of survey research methods*. Key Informant. Los ...nc. https://doi.org/10.4135/9781412963947

...Bayala, J., Huth, N. I., van Noordwijk, M., ...g of tree–crop interactions: Challenges and development needs. *Agricultural Systems*, *142*, 51–69. https://doi.org/10.1016/j.agsy.2015.11.005

Maass Wofenson, K. D. (2013). *Coping with the food and agriculture challenge: smallholders' agenda: Preparations and outcomes of the 2012 United Nations Conference on Sustainable Development (Rio+20)*. Rome, Italy. Retrieved from Food and Agriculture Organisation of the United Nations website: http://www.fao.org/3/a-ar363e.pdf

Mcfadden, D. (Ed.) (1974). *Conditional logit analysis of qualitative choice behaviour*. Retrieved from https://eml.berkeley.edu/reprints/mcfadden/zarembka.pdf

Mfitumukiza, D., Barasa, B., & Ingrid, A. (2017). Determinants of agroforestry adoption as an adaptation means to drought among smallholder farmers in Nakasongola District, Central Uganda. *African Journal of Agricultural Research*, *12*(23), 2024–2035.

Mowo, J., Sinclair, F., & Garrity, D. (2014). *Improving Sustainable Productivity in Farming Systems and Enhanced Livelihoods through Adoption of Evergreen Agriculture in Eastern Africa*. Final project proposal. Nairobi, Kenya.

Mugagga, F., Kakembo, V., & Buyinza, M. (2012). Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. *CATENA*, *90*, 39–46. https://doi.org/10.1016/j.catena.2011.11.004

Muthuri, W. C., Makuralinda, A., Abayneh, D., Okia, C., Buyinza, J. [Joel], Hadgu, K., . . . Sinclair, F. L. (2017). *Final report: Improving sustainable productivity in farming systems and enhanced livelihoods through adoption of evergreen agriculture in eastern Africa shortened as 'Trees for food security' project (T4FS)*. Retrieved from Australian Centre for International Agricultural Research (ACIAR) website: www.worldagroforestry.org/file/6260/download?token=ZxXmU-5M

Mwangi, A., & Muthuri, M. [May] (2016). The external review of trees for food security project a success. *The Link*. Retrieved from http://www.worldagroforestry.org/downloads/Publications/PDFS/NL16070.pdf

Mwase, W., Sefasi, A., Njoloma, J., Nyoka, B. I., Manduwa, D., & Nyaika, J. (2015). Factors Affecting Adoption of Agroforestry and Evergreen Agriculture in Southern Africa. *Environment and Natural Resources Research*, *5*(2).

Nair, P. K. R. (1993). *An introduction to agroforestry*. Dordrecht, Boston: Kluwer Academic Publishers in cooperation with International Centre for Research in Agroforestry.

Nair, P. K. R., & Garrity, D. P. (2012). *Agroforestry - the future of global land use. Advances in agroforestry: v. 9*. Dordrecht, London: Springer.

Ndamani, F., & Watanabe, T. (2015). Farmers' Perceptions about Adaptation Practices to Climate Change and Barriers to Adaptation: A Micro-Level Study in Ghana. *Water*, *7*(12), 4593–4604. https://doi.org/10.3390/w7094593

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to Environmental Change: Contributions of a Resilience Framework. *Annual Review of Environment and Resources*, *32*(1), 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348

Okia, C., Buyinza, J. [Joel], Agaba, H. [Hillary], Muthuri, C., Kiptot, E. [Evelyn], Kinuthia, R., . . . Sinclair, F. (2016). *Trees for food security project: A glimpse of Uganda*. Retrieved from World Agroforestry Centre website: https://www.worldagroforestry.org/sites/default/files/outputs/Okia.pdf

Pandey, J. (2018). Deductive Approach to Content Analysis. In M. Gupta, M. Shaheen, & K. Prathap Reddy (Eds.), *Advances in Business Information Systems and Analytics. Qualitative practices for workplace data analysis* (pp. 145–169). Hershey PA: IGI Global. https://doi.org/10.4018/978-1-5225-5366-3.ch007

Paul, C., Weber, M., & Knoke, T. (2017). Agroforestry versus farm mosaic systems – Comparing land-use efficiency, economic returns and risks under climate change effects. *Science of the Toal Environment*, *587-588*, 22–35.

Pretty, J. (2008). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *363*(1491), 447–465. https://doi.org/10.1098/rstb.2007.2163

Rabiee, F. (2004). Focus-group interview and data analysis. *Proceedings of the Nutrition Society*, *63*(04), 655–660. https://doi.org/10.1079/PNS2004399

Rahn, E., Liebig, T., Ghazoul, J., van Asten, P. [Piet], Läderach, P., Vaast, P., . . . Jassogne, L. [Laurence] (2018). Opportunities for sustainable intensification of coffee agro-ecosystems along an altitudinal gradient on Mt. Elgon, Uganda. *Agriculture, Ecosystems & Environment*, *263*, 31–40. https://doi.org/10.1016/j.agee.2018.04.019

Ronner, E., Descheemaeker, K., Almekinders, C., Ebanyat, P., & Giller, K. E. (2018). Farmers' use and adaptation of improved climbing bean production practices in the highlands of Uganda. *Agriculture, Ecosystems and Environment*, *261*, 186–200.

Roo, N. D., Andersson, J. A., & Krupniks, T. J. (2019). On-farm trials for development impact? the organisation of research and the scaling of agricultural technologies. *Experimental Agriculture*, *55*(2), 163–184. https://doi.org/10.1017/S0014479717000382

Rutakumwa, R., Mugisha, J. O., Bernays, S., Kabunga, E., Tumwekwase, G., Mbonye, M., & Seeley, J. (2020). Conducting in-depth interviews with and without voice recorders: A comparative analysis. *Qualitative Research*, *20*(5), 565–581. https://doi.org/10.1177/1468794119884806

Scherr, S. J. (1991). On-farm research: the challenges of agroforestry. *Agroforestry Systems*, *15*(2-3), 95–110. https://doi.org/10.1007/BF00120183

Scherr, S. J., Shames, S., & Friedman, R. (2012). From climate-smart agriculture to climate-smart landscapes. *Agriculture & Food Security*, *1*(1), 12. https://doi.org/10.1186/2048-7010-1-12

Schoonenboom, J., & Johnson, R. B. (2017). How to Construct a Mixed Methods Research Design. *Kolner Zeitschrift Fur Soziologie Und Sozialpsychologie*, *69*(Suppl 2), 107–131. https://doi.org/10.1007/s11577-017-0454-1

Sheahan, M., & Barrett, C. B. (2014). *Understanding the Agricultural Input Landscape in Sub-Saharan Africa: Recent Plot, Household, and Community-Level Evidence.* Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/20346/WPS7014.pdf?sequence=1

Smily, S. (2015). Field Recording or Field Observation?: Audio Meets Method in Qualitative Research. *The Qualitative Report*, *20*(11), 1812–1822. Retrieved from https://core.ac.uk/download/pdf/51086982.pdf

Sommer, R., Bossio, D., Desta, L., Dimes, J., Kihara, J., Koala, S., & … & Winowiecki, L. (2013). Profitable and sustainable nutrient management systems for East and Southern African smallholder farming systems challenges and opportunities: a synthesis of the Eastern and Southern Africa situation in terms of past experiences, present and future opportunities in promoting nutrients use in Africa. Retrieved from https://repository.cimmyt.org/xmlui/bitstream/handle/10883/4035/99011.pdf?sequence=1

Tambo, J. A., & Wünscher, T. (2017). Farmer-led innovations and rural household welfare: Evidence from Ghana. *Journal of Rural Studies*, *55*, 263–274.

Tashakkori, A., & Teddlie, C. (2010). *Sage handbook of mixed methods in social & behavioral research* (2nd ed.). Los Angeles, London: SAGE.

Taylor, S., & Todd, P. A. (1995). Understanding Information Technology Usage: A Test of Competing Models. *Information Systems Research*, *6*(2), 144–176.

Uganda Bureau of Statistics (2016). The National Population and Housing Census 2014 – Main Report, Kampala, Uganda. Retrieved from file:///C:/Users/hp/Desktop/03_20182014_National_Census_Main_Report.pdf

UN (2015). The sustainable development goals (SDGs). Retrieved from https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals#

Van Noordwijk, M., Coe, R. [Ric], & Sinclair, F. (2016). *Central hypotheses for the third agroforestry paradigm within a common definition.* (Working Paper No. 233). Bogor, Indonesia. https://doi.org/10.5716/WP16079.PDF

Von Carlowitz, P. G. (1989). Agroforestry technologies and fodder production — concepts and examples. *Agroforestry Systems*, *9*(1), 1–16. https://doi.org/10.1007/BF00120151

Walker, C., & Baxter, J. (2019). Method Sequence and Dominance in Mixed Methods Research: A Case Study of the Social Acceptance of Wind Energy Literature. *International Journal of Qualitative Methods*, *18*, 1-14. https://doi.org/10.1177/1609406919834379

Yin, R. K. (2018). *Case study research and applications: Design and methods* (Sixth edition). Los Angeles: SAGE.

Zeweld, W., van Huylenbroeck, G., Tesfay, G., & Speelman, S. (2017). Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of Environmental Management*, *187*, 71–81

CHAPTER TWO

SOCIO-TECHNOLOGICAL FACTORS INFLUENCING SMALLHOLDER FARMERS' CHOICES OF AGROFORESTRY TECHNOLOGIES IN UGANDA'S EASTERN HIGHLANDS[1]

Abstract

In Sub-Saharan Africa, agroforestry has been identified as the most sustainable remedy to counter declining farm productivity. Over the last decades, researchers and other actors have promoted several agroforestry technologies to improve farm productivity. Sometimes, the promotion message provided through extension assumes a homogenous farmers' context. Smallholder farmers' social and farm contexts are heterogeneous. Farmers make different choices of which technologies fit their contexts. A range of factor categories influence and (re)shape choice decisions of smallholder farmers. In this chapter, I sought to articulate the importance of socio-technological factors shaping smallholder farmers' choices of specific agroforestry technologies on their farms. Knowledge of these factors provides insights that inform refined context-based extension messages, consequently enhancing the scaling-out of agroforestry technologies. The Decomposed Theory of Planned Behavior was used as the main framework to understand smallholder farmers' choice decisions among agroforestry technologies. I used a mixed methods approach. Quantitative data were collected from 277 randomly selected farming households. Qualitative data that complemented the quantitative was collected using focus group discussions. An Alternative-Specific Conditional Logit (ASCLOGIT) model was used to model smallholder farmers' agroforestry choices. Results indicated that the number of tree species desired by the smallholder farmer and the perceived value of the technology were the most critical factors commonly influencing smallholder farmers' choices of agroforestry technologies. The influence of other factors such as gender, the number of training sessions attended, total land owned, subjective norms and smallholder farmers' perception of own ability (perceived behaviour control)

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was technology-specific, suggesting the need to tailor agroforestry interventions to specific farmer categories.

Keywords: Choice decisions, farm productivity, conditional logit, focus groups, decomposed theory

2.1 Introduction

The declining trend of farm productivity among smallholder farmers in Sub-Saharan Africa is a significant concern for research and practice. Several factors have been attributed to this trend, including soil erosion, land degradation and unsustainable farming practices (Sheahan and Barrett, 2014). These impacts of these factors are worsened by climatic risks such as drought, flooding, landslides/mudslides, pests and diseases, which have become more prevalent (Bomuhangi et al., 2016; Mubangizi et al., 2017). Agroforestry is promoted among smallholder farmers as one of the promising remedies to counter these challenges. Agroforestry is defined differently by different scholars. According to Nair (1993), agroforestry is a collective name for land-use systems and practices in which trees are deliberately integrated with crops and/or animals on the same land management unit in a spatial or temporal arrangement. Most recently, van Noordwijk et al. (2016) defined agroforestry as a practice and science of the interface and interactions between agriculture and forestry, involving farmers, crops, livestock and forests/trees at multiple scales. This recent definition includes trees that are not necessarily planted but deliberately retained in agricultural landscapes. In the context of this study, the emphasis is given to trees that are deliberately planted in agricultural fields to supplement farm productivity by enhancing soil fertility, reducing soil erosion, diversifying farm products and sustaining yields (Coulibaly et al., 2017; Luedeling et al., 2016; Rahn et al., 2018).

Frequent mismatches have been observed between introduced technologies and the smallholder farmers' needs who have to make complex decisions in reallocating their limited resources (Genanew et al., 2018; Ssebaggala et al., 2017). These mismatches are common, especially where the generation of technology and its subsequent introduction to smallholder farmers follow a top-down approach (Iiyama et al., 2018). In such a case, farmers should have many alternatives to choose what suits their contexts. Availing options has been the case in promoting agroforestry among smallholder farmers. To help farmers integrate trees on their farms, experts have devised several agroforestry technologies, including woodlots, fodder-banks, intercropping, boundary planting, alley cropping, improved fallows, among others (Luedeling et al., 2016; Sinclair, 1999). Some may argue that these are not new technologies since farmers have been integrating trees on their farms in ways that mirror these technologies (Lamond et al., 2016). However, they translate into technologies since they are characterized by specific tree species, spatial and temporal arrangement, establishment and spacing, and management aspects unique from what farmers are used to (Gram et al., 2017; Von Carlowitz, 1989). Where smallholder farmers have chosen agroforestry technologies that suit their contexts, positive outcomes have been realized. In Ethiopia, for example, woodlots were found to maximize farm productivity and smallholder farmers' incomes (Kassie, 2016). This study focuses on three agroforestry technologies (boundary planting, intercropping and woodlot), predominantly used in Uganda's eastern highlands.

Several factors broadly categorized into socio-economic, institutional, technological and human-specific factors influence farmers' choice decisions about the new agricultural technologies to choose among alternatives (Mwangi and Kariuki, 2015). Technologies are socially constituted because they are supposed to be responsive to the plurality of interests, meanings, and people (Ahlborg et al., 2019; Feenberg, 2005). Therefore, when technologies get introduced into society, the factors influencing choice often come up due to the interactions of the social (human) and the technology's technical domains, hence the term "socio-technological factors" used in this study. The interaction between the potential users' social characteristics and the attributes of a technology influence choice decisions made by the ultimate user (Mignouna et al., 2011; Mwangi and Kariuki, 2015; Wandji et al., 2012; Zubair and Garforth, 2006). Studies that have examined the influence of socio-technological factors on choice decisions remain scanty in agroforestry. McGinty et al. (2008) found that farmers perceptions of their ability (also known as perceived behavioural control) and favourable evaluation of conservation contributed significantly to the intention to adopt or maintain agroforestry in Brazil. In a study that focused on on-farm plantation forestry in Uganda, Kiyingi et al. (2016) found out that landholdings, education, skills training, and farmers' perceptions significantly explained smallholders farmers' variation in their choice decisions to invest in on-farm plantation forestry. Studies like these have focused on agroforestry in general or a single technology. Yet, smallholder farmers often face a range of technologies and must choose those that suit their contexts. Moreover, information on the extent to which smallholder farmers' socio-technological contexts explain the agroforestry technologies on their farms is limited.

Therefore, the objective of this study was to generate information that would guide the development of context-based extension messages to promote the scaling-out of appropriate agroforestry technologies in the eastern highlands of Uganda. Suppose agroforestry technologies are to be taken up to scale for the advantage of improving farm productivity. In that case, it is critical for agroforestry promoters and policymakers to tailor their interventions towards specific smallholder farmers' categories. Specifically, the study aims to: (1) Describe the predominant agroforestry technologies; (2) determine the extent to which smallholder farmers' socio-technological contexts explain their choice of agroforestry technologies. This study contributes to the literature in threefold: (1) the study applies the Decomposed Theory of Planned Behavior and demonstrates that it offers a structured framework for understanding smallholder farmers' choice decisions of agroforestry technologies in a developing country context; (2) This study applies an Alternative-Specific Conditional Logit (ASCLOGIT) model to examine the extent to which smallholder farmers' socio-technological context explain their choices of agroforestry technologies; (3) the work underpins the importance of understanding smallholder farmers' socio-technological contexts in designing and implementing interventions aimed at scaling-out agroforestry technologies.

2.2 Theoretical framework

Over the decades, several theoretical models have been proposed and used to understand people's behaviour. One of the most known is the Theory of Planned Behavior (TPB) (Ajzen, 1991), which has been applied in the context of agriculture (Borges et al., 2014; Wauters et al., 2010). The TPB postulates that behavioural intentions are determined by attitudes, subjective norms and perceived behavioural control. However, the TPB has come under criticism from some scholars. It was found that the TPB is less predictive of behaviour when studies used a longitudinal design when the participants are not university students and when outcome measures were taken objectively rather than as a self-report (McEachan et al., 2011). Focusing on the health psychology domain, Sniehotta, Presseau, and Araujo-Soares (2014) argue that the Theory of Planned Behaviour (TPB; Ajzen, 1991) has outlived its' usefulness and should be retired because of its limited predictive validity. Others have criticised it for treating attitude as a unidimensional construct, which does not provide an accurate understanding of behavioural intentions (Moons and De Pelsmacker, 2015; Taylor and Todd 1995a). However, even stronger voices argue that extending not retiring the theory could be the best option (Connor, 2014). Based on a comprehensive review and synthesis of several theoretical models, Taylor and Todd (1995a) proposed the Decomposed Theory of Planned Behavior (DTPB), which has since been applied to understand technological choice decisions in a variety of fields, including agriculture (Aziz and Afaq, 2018; Gangwal and Bansal, 2016; Md Husin and Ab Rahman, 2016; Zahid and Din, 2019).

Drawing from the Innovation Diffusion Theory (Rogers, 1983) and the TPB (Ajzen, 1991), Taylor and Todd (1995a) decomposed attitude into three constructs to provide for an accurate way of understanding behavioural intentions (Kyere-Duodu and Yamoah, 2011): the perceived value of the behaviour, perceived ease of use of the behaviour and perceived compatibility of the behaviour. The perceived value of the behaviour is one's evaluation of its merits and ability to meet their needs and expectations; perceived ease of use is a measure of how comfortable the person can apply a behaviour, and compatibility of the behaviour is the degree to which an action is perceived as consistent with existing practices. The DTPB retains the other two constructs as applied by the TPB, i.e. subjective norms (referred to as peer influence in this study)- which describes the extent to which one is influenced by the views of other people or groups of people regarding the behavior; and perceived behavioral control (referred to as perception of own ability in the context of this study) – which refers to one's perception of their ability (e.g. having the necessary resources and opportunities) to perform a given behavior. This study applied the DTPB (Taylor and Todd, 1995a) as a framework to examine smallholder farmers choice decisions in agroforestry. The argument is that the DTPB is more applicable in a variety of situations; has better explanatory power in explaining behaviour; allows for the decomposition of belief variables, and is flexible enough for the incorporation of other explanatory variables (Hernandez and Mazzon, 2006; Kyere-Duodu and Yamoah, 2011; Taylor and Todd, 1995b). In the context of this study, smallholder farmers' choice decisions and continued usage of the agroforestry technologies mirror the actual behaviour as applied in the DTPB.

Based on the DTPB and in the context of this study, farmers would be more likely to choose an agroforestry technology when they perceive it to be easy to apply, consistent with existing practices and to offer more benefits (Mignouna et al., 2011; Moons and De Pelsmacker, 2015; Mwangi and Kariuki, 2015; Zubair and Garforth, 2006). Likewise, an agroforestry technology that carries positive opinions of other people, especially those close to the potential user (peers), would be perceived positively and thus more likely to be chosen by smallholder farmers (Aziz and Afaq, 2018; Zahid and Din, 2019). Also, a smallholder farmer's positive evaluation of their ability to use the new agroforestry technology on their farm, i.e. the conviction that one has the necessary resources (both material and non-material), would enhance its choice (McGinty et al., 2008; Zahid and Din, 2019). The word 'perceived' as used in the DTPB applied well in the context of this study, given that agroforestry is a long-term enterprise and most smallholder farmers in the study area had not fully realized the intended benefits but still had hanging expectations. In the context of this study, the theoretical foundation of the DTPB was extended to include: other social factors such as gender (referring to male or female), membership to a farmer group, off-farm income, marital status, agroforestry training sessions attended; and technological characteristics such as the number of tree species that can be incorporated using technology and size of land available for technology implementation, that are hypothesized to influence choice decisions of technologies (Kiyingi et al., 2016; Kutia et al., 2019; Mignouna et al., 2011; Sanou et al., 2017).

2.3 Methodology

2.3.1 Study area and sampling

The study was conducted in the eastern highlands of Uganda (Figure 1) due to the history of decline in productivity of once very fertile and productive volcanic soils. Manafwa and Namisindwa were the study districts owing to an excellent interface of the communities with different actors (government and non-government) that promoted agroforestry technologies; dense population estimated at 900 persons per square kilometre (UNEP, 2014) that has resulted in the subdivision of once large farms into small landholdings along lineages; and a reportedly receptive community in embracing agroforestry technology (Barrios and Coe, 2014). The districts form part of the Trees for Food Security (T4FS) project sites – an Australian Centre for International Research (ACIAR) funded project aimed at improving household food security and smallholder livelihoods through the widespread use of appropriate agroforestry technologies. Currently, in its second phase, the T4FS project is being implemented by World Agroforestry Centre (ICRAF) in partnership with the National Agricultural Research Organisation (NARO), World Vision (WV) and Makerere University (MAK). In consultation with key informants in each district (District Environmental Officer, District Agricultural Extension Workers and T4FS project staff), one sub-county was purposively selected from each district with priority to one with the perceived highest level of using agroforestry. From the selected sub-counties (Butta in Manafwa and Namabya in Namisindwa), the population (1,011 households) that participated in agroforestry training sessions and accessed tree seedlings formed the sampling frame. Sub-county officials (community development officer, agricultural extension workers and trees for food security project staff) knew the households that fell in this category and generated the list. Simple random sampling was used to select a sample of 277 farming households to participate in the cross-sectional survey following Krejcie and Morgan (1970).

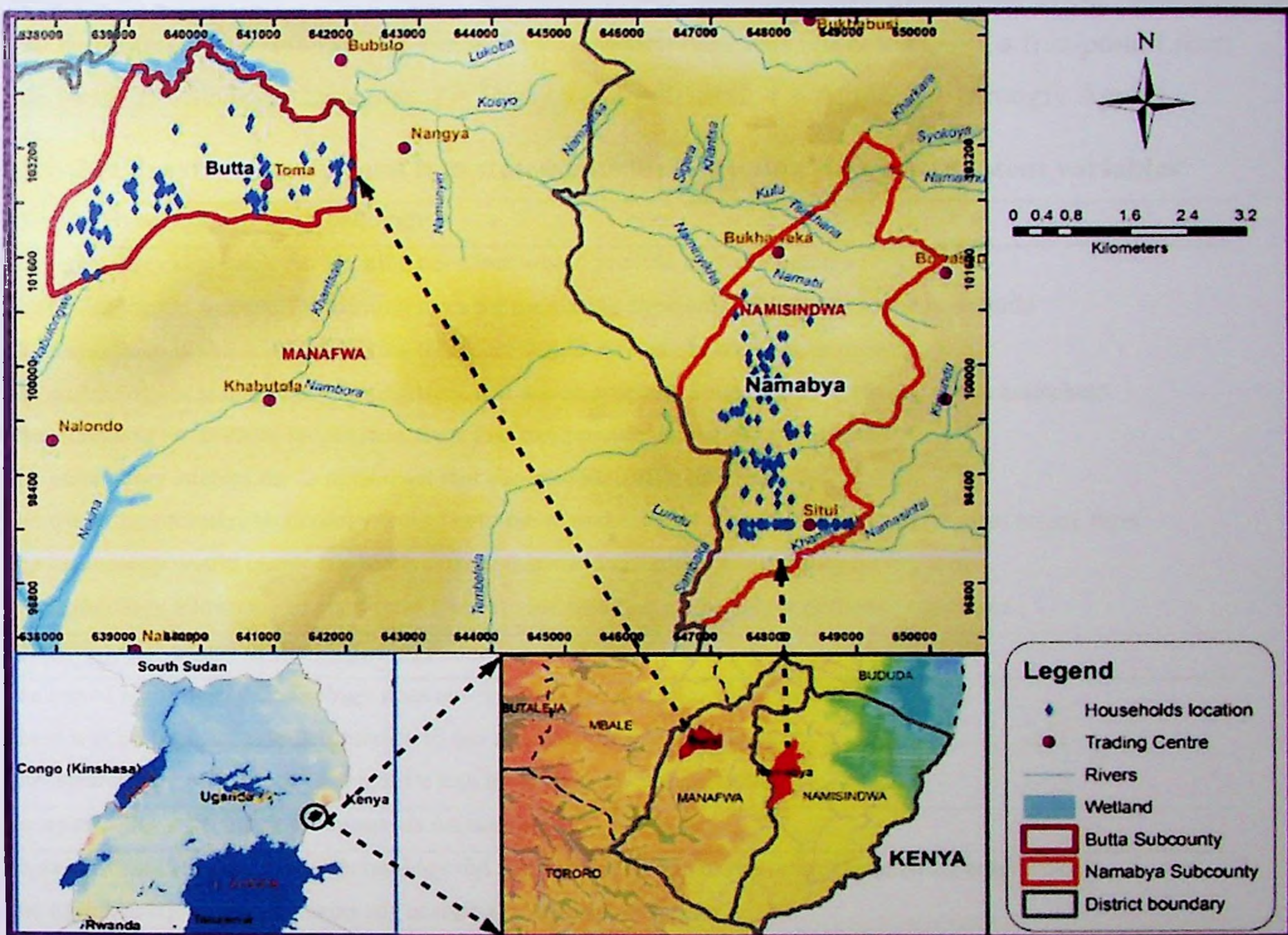

Figure 2.1: Map showing study sites and distribution of the sampled households

2.3.2 Data collection methods used

This study employed a cross-sectional survey to elicit data on smallholder farmers' choices of agroforestry technologies and the rationale for their choice decisions. To ensure mutual exclusivity among choices, given that sometimes farmers chose more than one alternative, the most predominant option (guided by smallholder farmers preference and on-farm observations) was considered. Before conducting a cross-sectional survey, a structured questionnaire was prepared and pre-tested with 20 farmers. The pre-testing was useful to improve the flow and clarity of questions. The final version of the questionnaire consisted of three sections: farm and household characteristics, farmers' description of the agroforestry technologies, and questions based on the DTPB. Because the study involved constructs (here referred to as latent variables) that could not be accurately measured with a single question, proxy variables were generated. Proxy variables were formulated into statements (Table 2.1) for which data was collected using a five-point Likert scale (with 1 = Strongly Disagree, 2 = Disagree, 3 = neutral, 4 = Agree, 5 = Strongly Agree).

Table 2.1: Proxies transformed into statements for collecting data about latent variables

The perceived value of the technology
The technology is suitable for planting trees that would provide herbal medicine
The technology is suitable for planting trees for increasing firewood availability in the household
The technology is suitable for planting trees that would increase household income
The technology is suitable for planting trees that are an essential source of food (fruits) to the household
The technology is suitable for planting trees that can provide fodder for my animals
The technology enables me to plant trees that can provide shade to crops
The use of agroforestry technology would help me to make use of degraded/unproductive sites on my farm
The technology would enable me to plant trees that would improve soil fertility on my farm
The technology allows me to plant trees that provide building materials for domestic structures
Perceived ease of use of the technology
The use of agroforestry technology does not require a lot of technical knowledge
There was no need for prior experience to use the agroforestry technology
The agroforestry practice did not require much labour to be implemented
Compatibility with other components on the farm
Implementing the agroforestry technology did not necessitate me to rearrange the existing enterprises
The agroforestry technology suits my household farming objectives
The agroforestry technology enables me to use tree species that have no direct effect on existing crops
The agroforestry technology is appropriate to the landscape location of the farm
Subjective norms (Peer influence)
I was influenced by the researchers (e.g. NARO, MAK, ICRAF) to use the agroforestry practice
I was influenced by the extension workers (local government) to use the agroforestry practice
The presence of other farmers who were already using the agroforestry technology influenced me to use it
I was influenced to use agroforestry technology because many Non-Government Organizations (NGOs) were promoting it in the area

Many Community-Based Organizations (CBOs) operating in the area influenced me to use the agroforestry technology
Perception of own ability (Perceived behavioural control)
Technical information received about the agroforestry technology was sufficient
Seedlings for tree species that are needed to implement the agroforestry technology are readily available
My previous experience in tree growing matched the agroforestry technology
The agroforestry technology was appropriate to the size of land we have
We have enough labour needed to implement the agroforestry technology
My choice of agroforestry technology was based on my determination and confidence in my abilities to implement it

Data on demographic and socio-economic variables such as gender, age, level of education, household size, household land size, membership to farmer groups, off-farm income and number of agroforestry training sessions attended during the last two years were also collected. We mainly interviewed the household head, who is more knowledgeable about the farm's decisions than any other household member. Each interview took about 2 hours to be completed.

Data from the survey was complemented by six focus group discussions (FGDs), one for each agroforestry technology. The focus group topics were developed following an analysis of the data collected during the survey to further explain some of the quantitative findings. Also, an in-depth understanding of the characteristics of the predominant agroforestry technologies implemented by the smallholder farmers was sought. The attendees in the focus groups were selected from participants in the cross-sectional survey. A total of 54 farmers (31 males and 23 females) who constituted the six focus groups were purposively selected based on their age (above 35 years), gender and choice of agroforestry technology. Smallholder farmers over 35 years were preferred because of their presumed experience in farming. Each focus group discussion consisted of 9 participants and lasted about two hours. Each attendee participated only in one focus group. Two moderators conducted the FGDs - one acting as a facilitator to guide the discussions and the other as an assistant documenting (notetaking) the discussion's general content. All FGDs were audio-recorded as a backup using a digital voice recorder, with all participants' consent.

2.3.3 Data analysis

The notes from the FGDs were refined using audio recordings to include as much detail as possible and ensure that the information accurately reflected the discussion's content. Deductive content analysis was used to analyze qualitative data from FGDs. Data were organized into themes to discover patterns emerging from the discussions, which could characterize the predominant agroforestry technology and explain other quantitative findings from the survey based on the study area's context.

Quantitative data from the survey were summarized into percentage, mean and standard deviation to describe the smallholder farmers' profile. Inferential statistics were used to analyze the relationships between variables and determine the extent to which farmers' socio-technological contexts influenced their choice of agroforestry technologies.

2.3.4 Empirical model

Exploratory factor analysis was used to generate the indices for the latent variables used in the model. The Kaiser-Mayor-Oklin measures of sampling adequacy (KMO) and Bartlett's Test of Sphericity which relates to the validity and suitability of responses, were used at a threshold of >0.5 and ≤0.05 respectively to check for suitability of data for factor analysis (Field, 2009). All factors with Eigenvalues of more than one were considered. Following Keil et al. (2008) and Banda et al. (2016), the first factor which extracted the highest variance was used as the proxy measure for the latent variable. The explanatory variables used for model estimation were mainly drawn from the literature on technological choice decisions in developing countries. To find out the multicollinearity between independent variables, collinearity diagnostic tests were done using the Variance Inflation Factor (VIF) values (at a threshold of VIF ≤ 5.00). Only non-collinear variables were included in model estimation to avoid biased estimates emanating from multicollinearity.

A farmer selected a predominant agroforestry practice from three alternatives: boundary planting, intercropping and woodlot, with no natural ordering. The dependent variable assumed a value of 1 for a choice and 0 otherwise. As such, the dependent variable in the model was categorical, unordered, and polytomous. Given this setup, an unordered utility model motivated by the random utility was preferred for the analytical framework. Smallholder farmers would choose alternative j if the utility from that alternative was higher than the utility from any other alternatives. Therefore, the probability for a specific choice was given by:

$$P_{ij} = \frac{\exp(X_{ij}\beta)}{\sum_{j=1}^{J} exp(X_{ij}\beta)} \qquad \text{for } i=1,\ldots\ldots, I \text{ and } j=1, \ldots\ldots J \qquad (1)$$

Where x_{ij} denotes a row vector of observations on variables of interest for respondent i and alternative j and β is a vector of parameters, usually different for each $j=1,..., J$.

The survey data in this analysis include both case-specific and alternative specific explanatory variables. Case-specific variables vary only across cases/respondents (e.g., gender, age, etc.). In contrast, alternative-specific variables vary across both cases/respondents and alternatives/choices (e.g. the number of tree species desired by the farmer in each technology and land size required for each technology) (Cameron and Trivedi, 2005). Given this nature of the explanatory variables, the Alternative-Specific Conditional Logit (ASCLOGIT) model (Mcfadden 1974) was chosen over the multinomial logit to determine the influence of socio-technological factors on farmers' choice of agroforestry technologies (Cameron and Trivedi, 2005; Greene 2012; Tanellari et al., 2015). When some of the regressors are alternative-specific, equation (1) becomes:

$$P_{ij} = \frac{\exp\ (X'_{ij}\beta + Z'_{i}Y)}{\sum_{j=1}^{J} \exp\ (X'_{ij}\beta + Z'_{i}Y)} \qquad \text{for } i=1,\ldots\ldots, I \text{ and } j=1, \ldots\ldots, J \qquad (2)$$

where x_{ij} are case-specific regressors, z_i are alternative-specific regressors and β, and y are vectors of parameters.

The ASCLOGIT model's estimation was undertaken by normalizing the intercropping category as the base alternative because it was the most chosen alternative (Greene 2012; Mcfadden, 1974). Marginal effects were used to determine the probability of selecting a given practice for a unit change in the predictor variable or a change from 0 to 1 in the case of discrete variables. STATA software version 13.0 was used to run the descriptive statistics and the ASCLOGIT model.

2.4 Results and discussions

2.4.1 Socio-economic and demographic characteristics of the farmers

The majority (59%) of the respondents were males (Table 2.2) because, within the sampled households, we targeted to interview household heads. It is common in such a patriarchal community in the study area (Kimaiyo et al., 2017) for men to be considered household heads even when this may not reflect a share of responsibility in the household. The result indicates that only 43% of the respondents were engaged in off-farm income-generating activities, with the common options being brickmaking, trading, carpentry, construction, fishing and food vending. The small proportion of farmers involved in off-farm income-generating activities indicates that households in the area are strongly dependent on agriculture, and farm productivity declines threaten their livelihoods. The proportion of farmers who were members of farmer groups was relatively small (32%), indicating that the group approach which the government is promoting cannot be relied upon as a strategy to promote agroforestry technologies in the study area. Most of the respondents (91%) were married, with both formal and informal marriages considered in this study. Most smallholder farmers were married probably because high social importance is attached to marriage among the Bamasaba (the predominant tribe in the study area) – with families arranging traditional marriages for their children (Makwa, 2021). The average age of the respondents was 46 years. They spent, on average, about seven years in school which translates to having completed primary level. This formal education level is adequate to interpret most of the extension messages passed on to the farmers. The average land size was about 3.7 acres. This land size is larger than the 2 acres reported in the region by Kimaiyo et al. (2017), possibly because this study targeted agroforestry farmers who could have had slightly more land that could have served as an incentive to take up some of the agroforestry technologies (Mubangizi et al., 2017). On average, farmers attended two agroforestry training sessions and had four tree species on their farms.

2.4.2 Smallholder farmers' description of the main agroforestry technologies

Table 2.3 highlights the most predominant agroforestry technologies in the eastern highlands of Uganda and their main characteristics. Following Nair (1993), the woody perennial (tree) forms the common denominator in agroforestry technologies. Therefore, the establishment and spacing of the trees and their role and function in a particular technology were part of the criteria used to characterize agroforestry technologies followed by the predominant crop enterprises and common tree species. A brief description of each agroforestry technology is highlighted below.

Boundary planting: Trees were planted systematically on the edges of plots for protective functions, e.g. windbreak; productive functions such as firewood; and cultural functions such as land delimitation. The tree species mainly used in the boundary planting were exotic such as

Neolamarckia cadamba, Grevillea robusta, Markhamia lutea and *Calliandra calothyrsus*. The most common indigenous tree species used in boundary planting was *Markhamia lutea*. According to the smallholder farmers, besides the products and services, these tree species were preferred for their fast-growing and adaptability to harsh conditions caused by grazing animals and neighbours. While trees on the boundary offer several products and services, they can also reduce adjacent crops' productivity and generate conflicts with neighbours (Bala et al., 2020; Sassen et al., 2013). Therefore, some hints on the features of appropriate trees based on area and people context should be carefully considered for boundary planting.

Table 2.2: Smallholder farmers' socio-economic and demographic characteristics

Characteristic	Percentage (n=277)	Mean (SD) (n=277)
Gender		
Male	58.8	
Female	41.2	
Off-farm income		
Yes	43.3	
No	56.7	
Group membership		
Yes	31.8	
No	68.2	
Marital status		
Married	91.3	
Unmarried	8.7	
Age of the respondent		46.49 (12.99)
Years spent in school		7.13 (3.69)
Total land owned		3.68 (1.98)
Number of agroforestry training sessions attended		2.20 (0.87)
Number of tree species		4.16 (1.30)

Intercropping: In this technology, trees are integrated with crop fields wither randomly or systematically for tree products (e.g. firewood, fruits, medicine) and protective functions (e.g. soil fertility) and services (soil fertility, shade) as desired by the smallholder farmers. The tree species were mainly intercropped with perennial crops (coffee and/or banana). Common tree species included Indigenous ones such as *Albizzia coriaria* and *Cordia africana* (used primarily for soil fertility and shade) and exotic ones – mainly fruit trees such as *Persea americana* and *Mangifera indica* (mainly used for fruits). Trees integrated with crops provide many services (Dai et al., 2017; Kuyah et al., 2016). Studies show that both *A. coriaria* and *C. africana* have been found by farmers to be highly favourable to crops like banana and coffee and are renowned for adding nutrients to the soil (Bukomeko et al., 2018; Gram et al., 2017; Kalanzi and Nansereko, 2015). Shade trees may also play an essential role in soil pest and disease control (Avelino et al., 2012). Although fruit trees, including *M. indica* and *P. americana* are not suitable to integrate into crop fields (Kalanzi and Nansereko, 2015; Zubair and Garforth, 2006), farmers preferred them for their direct contribution to household food security. During the FGDs, smallholder farmers also added that integrating fruit trees in crop fields instead of the boundary secures fruits against passers-by as they would find it harder to enter people's gardens.

Woodlot: Consisted of single or multiple tree species established on usually a smaller or less productive plot mainly for firewood, poles and timber. During the FGDs, farmers expressed that *Eucalyptus* spp. were the most used in the woodlot, followed by *Grevillea robusta* and *Neolamarckia cadamba*. Many woodlots were established on plots unsuitable for cultivating crops and would otherwise remain unused or less productive to the household. The tree species mentioned above were preferred for their fast growth and adaptability to less productive sites. *Eucalyptus* sprouts grow straight and have a smaller canopy, thus taking less space than other tree species. Therefore, Eucalyptus was preferred because it could sustain the production of firewood, poles, and timber – products highly demanded in local markets in the eastern highlands of Uganda (Gram et al., 2017).

Table 2.3. Smallholder farmers' description of the main agroforestry technologies

Criteria	Boundary planting	Intercropping	Woodlot
Establishment and spacing	Trees planted systematically on edges of plots Spacing varies from 2 m to 10 m	Trees integrated into crop fields Often wide spacing of up to 15 m to reduce competition with crops	Trees established in an area entirely set aside for tree growing Spacing can be as close as 0.5 x 0.5 m
Role and output from the trees	Demarcation, windbreak, soil conservation, boundary marking, firewood, fodder, timber, fruits	Fruits, fuelwood, wood, herbal medicine, soil improvement, shade	Landscape rehabilitation, firewood, timber, poles
Predominant crop enterprises*	Annual crops such as maize, beans, soybeans, potatoes, cassava	Perennial crops such as bananas, coffee	Annual crops such as yams and beans
Common tree species	Exotic: *Neolamarckia cadamba* Roxb, *Grevillea robusta* A.Cunn. ex R.Br., *Calliandra calothyrsus* Meisn. Indigenous: *Markhamia lutea* (Benth.) K.Schum	Indigenous: *Albizzia coriaria* Welw., *Cordia africana* Lam. Exotic: fruit trees such as *Persea americana* Mill., *Mangifera indica* L.	*Exotic: Eucalyptus* spp., *Grevillea* robusta A.Cunn. ex R.Br., *Neolamarckia cadamba* Roxb.

*Crops that were growing in the plot with boundary planting technology were captured

2.4.3 Relationship between socio-technological factors and choice of agroforestry technologies

Latent variables derived from the DTPB were indirectly estimated using their proxy variables. Therefore, factor analysis modelling was adopted to generate an index for each latent variable. Only proxies with eigenvalues of >1 constituted the index (Field, 2009). The Keiser-Meyer Olkin (KMO) measure of sampling adequacy for each latent variable was greater than 0.5, implying that the sample size was adequate for factor analysis. Bartlett's test of sphericity was significant ($P<0.01$) for all the latent variables indicating the suitability of data for factor analysis. In this study, the proxies' factor-score, which extracted the highest variance (Table 2.4), was used as the latent variable's generated index (Banda et al., 2016; Keil et al., 2008). Three proxies accounting for 52.9% of the variance were used to create an index for the technology's perceived value. One proxy, which accounted for 44.3% of the variance, was used to generate an index for ease of use of the technology. Two proxies accounting for 59.1% of the variance generated and index for perceived compatibility. Two proxies accounting for 50.8% were used to generate an index for subjective norms. Finally, three proxies accounting for 58.9% of the variance generated an index for perceived behavioural control. Latent variables and their indices were then used in the ASCLOGIT model estimation.

Table 2.4: Proxy variables used to generate indices for the latent variables

Model	Latent variable	KMO	Bartlett's Test of Sphericity	Proxy variable	Actual eigenvalue	% of variance explained	Cumulative %
1	Perceived value of the technology	0.647	0.000	firewood	2.43	27.0	27.0
				Income	1.29	14.3	41.3
				Shade	1.042	11.6	52.9
2	Ease of use	0.559	0.000	Technical knowledge not required	1.33	44.3	44.3
3	Perceived compatibility	0.538	0.02	Suits farmer's objectives	1.304	32.6	32.6
				No direct effect on crops	1.06	26.5	59.1
4	Subjective norms (Peer influence)	0.569	0.000	Other farmers	1.501	30.0	30.0
				NGOs	1.039	20.8	50.8
5	Perception of own ability (PBC)	0.565	0.001	Previous experience	1.444	24.1	24.1
				Availability of free seedlings	1.082	18.0	42.1
				Technical information received	1.011	16.8	58.9

The estimation of the ASCLOGIT model gave a Wald Chi-square (59.37), which was highly significant ($P<0.01$), suggesting that the chosen explanatory variables fitted the model reasonably well. The Pseudo R^2 (0.26) fell between 0.2 – 0.4, indicating a very good model fit (Mcfadden, 1977). The marginal effects of the ASCLOGIT model presented in Table 2.5 indicate the impact of each socio-technological factor on agroforestry technologies' choice decision holding all other factors constant. The number of tree species desired by the farmer in each technology and the perceived value were the most critical factors related to an agroforestry technology's choice. The effect of other socio-technological factors varies with technology.

Table 2.5: Influence of socio-technological factors on the probability of smallholder farmers' choice of agroforestry technology

Variable	Boundary planting	Intercropping	Woodlot
Alternative-specific			
Number of tree species needed by the smallholder farmer	0.0271***	0.0325***	0.0208***
Case-specific			
Sex[b]	0.070*	0.015	0.085**
Marital status	0.004	0.023	-0.026
Years spent in school	0.007	-0.013	0.006
Membership to a group	0.041	-0.061	0.021
Off-farm income	-0.003	0.056	-0.053
Number of agroforestry training sessions attended	-0.098**	0.090	0.008
Total land owned (acres)	0.005	0.011	0.017**
Perceived value of the technology	0.029***	0.091***	0.043***
Ease of use of a technology	0.026	0.004	0.022
Compatibility with crops	0.019	0.002	0.021
Subjective norms (peer influence)	0.027**	0.027	0.000
Perceived behavioral control (PBC)	0.031**	0.034*	0.003

- ([b]) marginal effect as sex (binary variable) changes from 0 to 1.
- *, ** and *** indicate statistical significance level at 10%, 5% and 1% respectively

A one-unit increase in the number of tree species a farmer desires to plant in each agroforestry technology increases the technology's probability of being selected. The highest effect occurs in the intercropping technology (3.3 percentage points), followed by boundary planting (2.7

percentage points) and, lastly, woodlot (2.1 percentage points). The high effect is because smallholder farmers have several needs, including fruits, poles, timber, firewood, soil conservation and shade. Even a multipurpose tree species may not offer all the smallholder farmers' anticipated benefits (Gram et al., 2017). Therefore, smallholder farmers who are constrained by land in the first place would prefer to choose an agroforestry technology where they could integrate several tree species to tap into a variety of anticipated tree benefits (Lamond et al., 2016; Vandreé and Bokelmann, 2017).

The sex of the smallholder farmer significantly increases the choice probability of boundary planting and woodlot technologies but not intercropping. A discrete change in sex from 0 to 1 (female to male) increases the choice probability of boundary planting and woodlot technology by 7.0 percentage points and 8.5 percentage points, respectively, with the most prominent effect occurring in the woodlot. Previous studies have shown sex to significantly influence agroforestry choice decisions (Kiyingi et al., 2016; Wambugu et al., 2011). Men in the eastern highlands have better access to land than their women counterparts due to socio-cultural norms that perpetuate male inheritance of property (Kimaiyo et al., 2017). The security of tenure to land commonly attained through succession makes them more likely than their female counterparts to choose the woodlot technology where associated benefits are long term. Also, men are more likely to select the woodlot technology associated with income-generating products like timber and poles (Kassie et al., 2013; Kiyingi et al., 2016; Mignouna et al., 2011). The idea of men dominating income-generating activities is supported by Anderson et al. (2016), who argue that men tend to engage in income-generating enterprises while women are more involved in providing food to the household. Men are also more likely than women to choose boundary planting technology because integrating trees along plot boundaries has evolved in parallel with a customary practice of securing land for which rights of use have been acquired (Dewees, 1995). The trees in the boundary planting technology serve as robust physical markers that designate land boundaries. It emerged from FGDs that as default owners of the land, men know better than women the land plots' actual boundaries.

The number of agroforestry training sessions attended significantly decreases the choice probability of boundary planting than other agroforestry technologies. A one-unit increase in the number of agroforestry training sessions attended decreases the choice probability for boundary planting by 9.8 percentage points. As smallholder farmers attend more agroforestry training sessions, their likelihood of choosing the boundary planting technology decreases in favour of other technologies. It's important to note that most of the trainings were conducted under the Trees for Food Security Project, which emphasised smallholder farmers' increased food and income security. Under this context, the food and income objectives seemed to be achieved better using intercropping and woodlot technologies than the boundary planting. Before being trained, the boundary technology would possibly appeal to smallholder farmers who feared that trees negatively impact crops if planted nearby (Mwangi and Kariuki, 2015). Agroforestry trainings empowered smallholder farmers with knowledge about tree-crop interactions and tree management options to evaluate their technological options (Anang et al., 2015; Nigussie et al., 2017). Therefore, it is possible that as farmers received more agroforestry training sessions, they were more likely to choose intercropping and woodlot technologies as opposed to boundary planting.

Total land owned significantly increases the choice probability of the woodlot as compared to other alternatives. A unit increase in the number of acres of land owned by the smallholder farmer increases the choice probability for the woodlot option by 1.7 percentage points. There is great importance attached to land size concerning the woodlot technology choice because it requires smallholder farmers to designate part of their land exclusively to tree growing. Other studies have also highlighted the importance of land in influencing smallholder farmers' choice decisions regarding new agricultural technologies (Kiyingi et al., 2016; Nigussie et al., 2017). During the FGDs, smallholder farmers argued that their priority is to secure food for their households first rather than take risks investing their time and labour in technologies where the anticipated benefits are in the long term. Smallholder farmers' argument reinforces previous studies' findings, highlighting that most farmers' overriding priority is food security (Meijer et al., 2015). Since the woodlot technology does not directly contribute to food security, at least soon, its choice probability can only be enhanced where land is less of a constraint to a smallholder farmer (Kiyingi et al., 2016).

The perceived value of technology significantly increases the choice probability of all the agroforestry technologies. A positive perception of the technology's value increases the choice probability of boundary planting, intercropping and woodlot by 2.9, 9.1 and 4.3 percentage points, respectively. The higher the technology's perceived value, the more likely the farmer chooses it over other technologies. The most significant influence occurs in intercropping as compared to other technologies. This is possibly because smallholder farmers tend to grow precious tree species in plots that are easily monitored with other crops (Whitney et al., 2017). The intercropping technology ensures that trees planted can be monitored and managed alongside crops. Thus, highly valued tree species such as fruit trees that directly contribute to the household's food and income security are often integrated into crop fields (Kalanzi and Nansereko, 2015; Nyaga et al., 2015). On the other hand, once smallholder farmers have secured food, they may try technologies with higher anticipated economic value. This explains the increase in the choice probability of the woodlot technology where tree species such as *Eucalyptus* spp., *Grevillea robusta* and *Neolamarckia cadamba* that produce highly marketable wood products such as timber and poles, are integrated as observed in other studies (Nath et al., 2016; Nyaga et al., 2015).

Subjective norms (Peer influence) significantly increased the choice probability of the boundary planting technology by 2.7 percentage points but not intercropping and woodlot technologies. This could mean that smallholder farmers using boundary planting technology were more often influenced by their peers. It could also indicate the sensitivity of tree planting at the boundary of agricultural fields. The aspect of some farmers influencing their peers regarding technological choice decisions has been supported by many studies in agriculture (Aziz and Afaq, 2018; McGinty et al., 2008; Meijer et al., 2015; Zahid and Din 2019; Zubair and Garforth, 2006). The results are more varied in studies related to agroforestry. A study by Ofoegbu and Ifejika (2017), for example, reported that peer influence had the most significant effect on farmers' choice of sustainable forest use and management options in South Africa. A recent study by Buyinza et al. (2020) did not find peer influence as a significant factor in influencing farmers' intention to integrate trees in their coffee plantations in the Mt. Elgon region of Uganda. In the context of this study, smallholder farmers seem to have been more familiar with the boundary planting technology. It was possibly more natural for them to use simple messages to influence their peers within the community (Kiptot et al., 2006).

On average, a unit increase in a smallholder farmer's positive perception of their ability (perceived behavioural control) increases the choice probability for each of the boundary planting and intercropping technologies by 3.1 and 3.4 percentage points, respectively but not woodlot. Many smallholder farmers don't believe that they have enough land to designate a plot exclusively for woodlot establishment because their main priority is to secure food. During the FGDs, farmers were found to have more previous experience in planting or retaining trees along the boundary of their farms or in their crop fields. This made it easy for smallholder farmers to embrace boundary planting and intercropping technologies. It has been noted that farmers are risk-averse and tend to select technologies they are more familiar with (Kidane et al., 2019; Mukasa, 2018). In the case of the boundary planting and intercropping, our results support earlier findings that show that smallholder farmers' choice decisions of new agricultural technologies are influenced by the positive perception of their abilities to implement them (Denkyirah et al., 2017; Md Husin and Ab Rahman, 2016; Meijer et al., 2015; Van Hulst and Posthumus, 2016).

2.5 Conclusion

This chapter makes two main contributions. First, it describes the three most predominant agroforestry technologies in the eastern highlands of Uganda: (1) boundary planting, (2) intercropping, and (3) woodlot. The study identified four main criteria for describing the predominant agroforestry technologies; the arrangement of the tree component, their roles and function, the dominant crop enterprises incorporated, and the common tree species in each technology. Regardless of the agroforestry technology, the smallholder farmers' objective is to ensure timber, fruits and firewood, and services such as soil fertility and shade to other crops.

Second, the study provides vital empirical insights into how smallholder farmers' socio-technological contexts explain their agroforestry technology choice decisions in a scenario where smallholder farmers had been trained and exposed to the technologies through demonstration trials. Our results show that the most critical socio-technological factor which cut across the three agroforestry technologies is the perceived value of the technology as informed by its ability to contribute to firewood availability, household income and shading of crops. This was followed by the perception of their ability (PBC) as informed by the smallholder farmer's experience, availability of free tree seedlings and technical information received from the technology promoters. Contrary to the literature on technology use, ease of use and compatibility were not found to significantly influence smallholder farmers' choices of agroforestry technologies in this study. This was possible because smallholder farmers were trained about the technologies and actively participated in demonstration trials. Technologies were thus less complicated to them in terms of application to their fields.

The findings of this study can have implications for the promotion of agroforestry. This study shows a positive impact of peer influence on smallholder farmers' choice of boundary planting technology. Peer influence in technology adaptation and agricultural dissemination has been a basis for developing farmer-led extension approaches, but this has not been tried out to promote agroforestry. Therefore, agroforestry extension programmes need to capitalize on peer influence to design farmer to farmer extension messages for promoting the boundary planting technology in the eastern highlands of Uganda. The significant influence of perceived behavioural control on choice decisions of boundary planting and intercropping implies that when smallholder farmers believe in their abilities to implement a particular technology, they are more likely to choose it. This means that when promoting boundary planting and intercropping, planning of extension messages should also focus on building the confidence of smallholder farmers to use the resources they have.

This study showed that the number of training sessions attended decreased the choice probability of the boundary planting technology favouring intercropping and woodlot, which were more rewarding to food and income security. This relationship between the number of training sessions attended and the choice of agroforestry technologies highlights the need to emphasise the capacity building of smallholder farmers among policy directions.

References

Ahlborg, H., Ruiz-Mercado, I., Molander, S., & Masera, O. (2019). Bringing Technology into Social-Ecological Systems Research—Motivations for a Socio-Technical-Ecological Systems Approach. *Sustainability*, *11*(7), 2009. https://doi.org/10.3390/su11072009

Ajzen, I. (1991). The Theory of Planned Behavior. *Organisational Behavior and Human Decision Processes*, *50*, 179–211.

Anang, B. T., Sipilainen, T., Backman, S., & Kola, J. (2015). Factors influencing smallholder farmers access to agricultural microcredit in Northern Ghana. *African Journal of Agricultural Research*, *10*(24), 2460–2469. https://doi.org/10.5897/AJAR2015.9536

Anderson, C. L., Reynolds, T. W., & Gugerty, M. K. (2016). Husband and Wife Perspectives on Farm Household Decision-making Authority and Evidence on Intra-household Accord in Rural Tanzania. *World Development*, *90*, 169–183.

Avelino, J., ten Hoopen, G. M., & DeClerck, F. A. (2012). Ecological mechanisms for pest and disease control in coffee and cacao agroecosystems of the Neotropics. In Ecosystem Services from Agriculture and Agroforestry (pp. 125-152). Routledge.

Aziz, S., & Afaq, Z. (2018). Adoption of Islamic banking in Pakistan an empirical investigation. *Cogent Business and Management*, *5*(1548050).

Bala, P., Ojunga, S. O., Okumu, J., Kisiwa, A., Langat, D., & Nyambati, R. (2020). Tree-Based Conflict Management Mechanism Among Small Landholders in Agroforestry Systems of Kenya. *East African Journal of Forestry and Agroforestry*, *2*(2), 24–39. https://doi.org/10.37284/eajfa.2.2.214

Banda, T. F., Phiri, M. R., Mapemba, L. D., & Maonga, B. B. (2016). *Household resilience to drought: The case of Salima district in Malawi*. FPRI working paper 14, May 2016. Retrieved from http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130372/filename/130583.pdf

Barrios, E. [Edmundo], & Coe, R. [Richard] (2014). *Participatory trials design workshop report*. Mbale, Uganda. Retrieved from World Agroforestry Centre (ICRAF) Uganda website: http://www.worldagroforestry.org/sites/default/files/participatory%20Trials%20Design%20workshop-Rwanda%202013.pdf

Bomuhangi, A., Nabanoga, G., Namaalwa, J. J., Jacobson, M. G., Abwoli, B., & Wich, S. (2016). Local communities' perceptions of climate variability in the Mt. Elgon region, eastern Uganda. *Cogent Environmental Science*, *2*(1), 1168276. https://doi.org/10.1080/23311843.2016.1168276

Borges, J. A. R., Oude Lansink, A. G., Marques Ribeiro, C., & Lutke, V. (2014). Understanding farmers' intention to adopt improved natural grassland using the theory of planned behavior. *Livestock Science*, *169*, 163–174. https://doi.org/10.1016/j.livsci.2014.09.014

Bukomeko, H., Jassogne, L., Kagezi, G. H., Mukasa, D., & Vaast, P. (2018). Influence of shaded systems on Xylosandrus compactus infestation in Robusta coffee along a rainfall gradient in Uganda. *Agricultural and Forest Entomology*, *20*(3), 327–333. https://doi.org/10.1111/afe.12265

Buyinza, J., Nuberg, I. K., Muthuri, C. W., & Denton, M. D. (2020). Psychological Factors Influencing Farmers' Intention to Adopt Agroforestry: A Structural Equation Modeling Approach. *Journal of Sustainable Forestry*, *45*(6), 1–12. https://doi.org/10.1080/10549811.2020.1738948

Cameron, A. C., & Trivedi, P. K. (2005). *Microeconometrics : Methods and Applications*. New York: Cambridge University Press. Retrieved from http://www.centroportici.unina.it/centro/Cameron&Trivedi.pdf.

Conner, M (2014) Extending not retiring the theory of planned behaviour: a commentary on Sniehotta, Presseau and Araújo-Soares. Health Psychology Review, 9 (2). pp. 141-145. ISSN 1743-7199

Coulibaly, J. Y., Chiputwa, B., Nakelse, T., & Kundhlande, G. (2017). Adoption of agroforestry and the impact on household food security among farmers in Malawi. *Agricultural Systems*, *155*, 52–69.

Dai, X., Pu, L., & Rao, F. (2017). Assessing the Effect of a Crop-Tree Intercropping Program on Smallholders' Incomes in Rural Xinjiang, China. *Sustainability*, *9*(9), 1542. https://doi.org/10.3390/su9091542

Denkyirah, E. K., Okoffo, E. D., Adu, D. T., & Bosompem, O. A. (2017). What are the drivers of cocoa farmers' choice of climate change adaptation strategies in Ghana? *Cogent Food & Agriculture*, *3*, 1–21.

Dewees, P. A. (1995). Trees and Farm Boundaries: Farm Forestry, Land Tenure and Reform in Kenya. *Journal of the International African Institute*, *65*(2), 217–237.

Feenberg, A. (2005). Critical theory of technology: An overview. *Tailoring Biotechnologies*, *1*(1), 47–64. Retrieved from https://www.sfu.ca/~andrewf/books/critbio.pdf

Field, A. (2009). *Discovering statistics using SPSS: (and sex, drugs and rock 'n' roll)* (3rd ed.). Los Angeles: SAGE Publications.

Gangwal, N., & Bansal, V. (2016). Application of decomposed theory of planned behaviour for M-commerce adoption in India. In S. Hammoudi, L. Maciaszek, M. M. Missikoff, O. Camp, & J. Cordeiro (Eds.), *Proceedings of the 18th International Conference on Enterprise Information Systems (ICEIS 2016)* (Vol. 2, pp. 357–367). Rome, Italy: SCITEPRESS - Science and Technology Publications Lda.

Gram, G., Vaast, P., van der Wolf, J., & Jassogne, L. (2017). Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in Mount Elgon, Uganda. *Agroforestry Systems*, *32*(4), 443. https://doi.org/10.1007/s10457-017-0111-8

Greene, W. H. (2012). *Econometric analysis* (7th ed.). Boston: Prentice Hall.

Hernandez, J. M. C., & Mazzon, J. A. (2006). Adoption of internet banking: proposition and implementation of an integrated methodology approach. *International Journal of Bank Marketing*, *25*(2), 72–88.

Iiyama, M., Mukuralinda, A., Ndayambaje, J. D., Musana, B. S., Ndoli, A., Mowo, J. G., . . . Ruganzu, V. (2018). Addressing the paradox – the divergence between smallholders' preference and actual adoption of agricultural innovations. *International Journal of Agricultural Sustainability*, *16*(6), 472–485. https://doi.org/10.1080/14735903.2018.1539384

Kalanzi, F., & Nansereko, S. (2015). Exploration of farmers' tree species selection for coffee agroforestry in Bukomansimbi district of Uganda. *International Journal of Research on Land-Use Sustainability*, *1*, 9–17.

Kassie, G. W. (2016). Agroforestry and land productivity: Evidence from rural Ethiopia. *Cogent Food & Agriculture*, *2*(1), 99–116. https://doi.org/10.1080/23311932.2016.1259140

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technology Forecasting and Social Change*, *80*, 525–540.

Keil, A., Zeller, M., Wida, A., Sanim, B., & Birner, R. (2008). What determines farmers' resilience towards ENSO-related drought? An empirical assessment in Central Sulawesi, Indonesia. *Climatic Change*, *86*(3-4), 291–307. https://doi.org/10.1007/s10584-007-9326-4

Kidane, S. M., Lambert, D. M., Eash, N. S., Roberts, R. K., Thierfelder, C., & (None) (2019). Conservationn agricuture and maize production risk: The case of Mozambique smallholders. *Agronomy Journal*, *111*(3), 1–11.

Kimaiyo, J., Kiptot, E., Tanui, J., Oduol, J., Kegode, H., Isubikalu, P., . . . Okia, C. (2017a). *Livelihood analysis of households in Manafwa and Kapchorwa*. Research Report. Nairobi, Kenya.

Kimaiyo, J. (., Kiptot, E., Tanui, J., Oduol, J., Kegode, H., Isubikalu, P., . . . Okia, C. (2017b).. Livelihood analysis of households in Manafwa and Kapchorwa. Nairobi, Kenya. Retrieved from World Agroforestry Centre website: http://www.worldagroforestry.org/sites/agroforestry/files/out-put/attachments/Livelihood%20analysis_Uganda_Final%20report.pdf

Kiptot, E., Franzel, S., Hebinck, P., & Richards, P. (2006). Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. *Agricultural Systems*, *68*, 167–179.

Kiyingi, I., Edriss, A., Phiri, M., Buyinza, M., & Agaba, H. (2016). Adoption of On-Farm Plantation Forestry by Smallholder Farmers in Uganda. *Journal of Sustainable Development*, *9*(2), 153–161. https://doi.org/10.5539/jsd.v9n2p153

Krejcie, R. V., & Morgan, D. W. (1970). Determing sample size for research activities. *Educational and Psychological Measurement*, *30*, 607–610.

Kutia, S., Chauhdary, S. H., Iwendi, C., Liu, L., Yong, W., & Bashir, A. K. (2019). Socio-Technological Factors Affecting User's Adoption of eHealth Functionalities: A Case Study of China and Ukraine eHealth Systems. *IEEE Access*, *7*, 90777–90788. https://doi.org/10.1109/ACCESS.2019.2924584

Kuyah, S., Öborn, I. [Ingrid], Jonsson, M., Dahlin, A. S., Barrios, E. [Edmundo], Muthuri, C., . . . Sinclair, F. L. (2016). Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *55*, 1–19. https://doi.org/10.1080/21513732.2016.1214178

Kyere-Duodu, K., & Yamoah, D. D. (2011). *Adoption of internet banking among Ghanaian consumers: a study using decomposed theory of planned behaviour* (Master's thesis). Lulea university of technology, Sweden. Retrieved from http://ltu.diva-portal.org/smash/get/diva2:1020286/FULLTEXT02.pdf

Lamond, G., Sandbrook, L., Gassner, A., & Sinclair, F. L. (2016). Local knowledge of tree attributes underpins species selection on coffee farms. *Experimental Agriculture*, *55*(S1), 35–49. https://doi.org/10.1017/S0014479716000168

Luedeling, E., Smethurst, P. J., Baudron, F., Bayala, J., Huth, N. I., van Noordwijk, M., . . . Sinclair, F. L. (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs. *Agricultural Systems*, *142*, 51–69. https://doi.org/10.1016/j.agsy.2015.11.005.

Makwa, D. (2021). Musicking and Dancing Imbalu at Namasho: Enacting Indigenous Education Among the Bagisu, Uganda. Yearbook for Traditional Music, 53, 127-154. doi:10.1017/ytm.2021.28.

McEachan, R. R. C., Conner, M., Taylor, N., & Lawton, R. J. (2011). Prospective prediction of health-related behaviors with the theory of planned behavior: A meta-analysis. Health Psychology Review, 5, 97–144. 10.1080/17437199.2010.521684

Mcfadden, D. (Ed.) (1974). Conditional logit analysis of qualitative choice behaviour. Retrieved from https://eml.berkeley.edu/reprints/mcfadden/zarembka.pdf

Mcfadden, D. (1977). Qualitative methods for analyzing travel behavior of individuals: some recent developments. *Cowles Foundation Discussion Paper No. 474*. University of California: Berkeley: Institute of Transportation Studies.

McGinty, M. M., Swisher, M. E., & Alavalapati, J. (2008). Agroforestry adoption and maintenance: self-efficacy, attitudes and socio-economic factors. *Agroforestry Systems*, *73*(2), 99–108. https://doi.org/10.1007/s10457-008-9114-9

Md Husin, M., & Ab Rahman, A. (2016). Predicting intention to participate in family takaful scheme using decomposed theory of planned behaviour. *International Journal of Social Economics*, *43*(12), 1351–1366. https://doi.org/10.1108/IJSE-03-2015-0074

Meijer, S. S., Catacutan, D., Sileshi, G. W., & Nieuwenhuis, M. (2015). Tree planting by smallholder farmers in Malawi: Using the theory of planned behaviour to examine the relationship between attitudes and behaviour. *Journal of Environmental Psychology*, *43*, 1–12. https://doi.org/10.1016/j.jenvp.2015.05.008

Mignouna, D. B., Manyong, V. M., Mutabazi, K. D. S., & Senkondo, E. M. (2011). Determinants of adopting imazapyr-resistant maize for Striga control in Western Kenya: A double-hurdle approach. *Journal of Development and Agricultural Economics*, *3*(11), 572–580.

Moons, I., & De Pelsmacker, P. (2015). An Extended Decomposed Theory of Planned Behaviour to Predict the Usage Intention of the Electric Car: A Multi-Group Comparison. *Sustainability*, *7*, 6212–6245.

Mubangizi, N., Kyazze, F. B., & Mukwaya, P. I. (2017). Smallholder farmers' perception and adaptation to rainfall variability in Mt. Elgon region, eastern Uganda. *International Journal of Agricultural Extension*, *5*(3), 103–117.

Mukasa, A. N. (2018). Technology adoption and risk exposure among smallholder farmers: Panel data evidence from Tanzania and Uganda. *World Development*, *105*, 299–309. https://doi.org/10.1016/j.worlddev.2017.12.006

Mwangi, M., & Kariuki, S. (2015). Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *Journal of Economics and Sustainable Development*, *6*(5), 208–216. Retrieved from https://pdfs.semanticscholar.org/8e9b/28e14286f65a9168738a97c74a256bc8e4c3.pdf

Nair, R. P. (1993). *An introduction to agroforestry*. Dordrecht, Netherlands: Kluwer Academic Publisher.

Nath, C. D., Schroth, G., & Burslem, D. F. (2016). Why do farmers plant more exotic than native trees? A case study from the Western Ghats, India. *Agriculture, Ecosystems & Environment*, *230*, 315–328. https://doi.org/10.1016/j.agee.2016.05.013

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tsubo, M., . . . Abele, S. (2017). Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia. *Land Use Policy*, *67*, 57–64.

Nyaga, J. [J.], Barrios, E. [E.], Muthuri, C. W. [C. W.], Öborn, I. [I.], Matiru, V., & Sinclair, F. L. [F. L.] (2015). Evaluating factors influencing heterogeneity in agroforestry adoption and practices within smallholder farms in Rift Valley, Kenya. *Agriculture, Ecosystems & Environment*, *212*, 106–118. https://doi.org/10.1016/j.agee.2015.06.013

Ofoegbu, C., & Ifejika, C. S. (2017). Assessing rural peoples' intention to adopt sustainable forest use and management practices in South Africa. *Journal of Sustainable Forestry*, *36*(7), 729–746. https://doi.org/10.1080/10549811.2017.1365612

Rahn, E., Liebig, T., Ghazoul, J., van Asten, P., Läderach, P., Vaast, P., . . . Jassogne, L. (2018). Opportunities for sustainable intensification of coffee agro-ecosystems along an altitudinal gradient on Mt. Elgon, Uganda. *Agriculture, Ecosystems & Environment*, *263*, 31–40. https://doi.org/10.1016/j.agee.2018.04.019

Rogers, E. M. (1983). *Diffusion of innovations* (3rd ed.). New York, London: Free Press; Collier Macmillan. Retrieved from https://teddykw2.files.wordpress.com/2012/07/everett-m-rogers-diffusion-of-innovations.pdf

Sanou, L., Savadogo, P., Ezebilo, E. E., & Thiombiano, A. (2017). Drivers of farmers' decisions to adopt agroforestry: Evidence from the Sudanian savanna zone, Burkina Faso. *Renewable Agriculture and Food Systems*, *34*(2), 116–133.

Sassen, M., Sheil, D., Giller, K. E., & Braak, C. J. ter (2013). Complex contexts and dynamic drivers: Understanding four decades of forest loss and recovery in an East African protected area. *Biological Conservation*, *159*, 257–268. https://doi.org/10.1016/j.biocon.2012.12.003

Sheahan, M., & Barrett, C. B. (2014). *Understanding the Agricultural Input Landscape in Sub-Saharan Africa: Recent Plot, Household, and Community-Level Evidence*. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/20346/WPS7014.pdf?sequence=1

Sinclair, F. L. (1999). A general classification of agroforestry practice. *Agricultural Systems*, *46*, 161–180.

Sniehotta, F.F, Justin Presseau, J. & Araújo-Soares, V. (2014). Time to retire the theory of planned behaviour. Health Psychology Review, 8:1, 1-7, DOI: 10.1080/17437199.2013.869710

Ssebaggala, G. L., Kibwika, P., & Kyazze, F. B. (2017). Contextual mismatch of interventions for reduction of postharvest losses in rice: Farmer perceptions, practices and innovations in Eastern Uganda. *Agricultural Science Digest - a Research Journal*, *37*(2). https://doi.org/10.18805/asd.v37i2.7988

Tanellari, E., Bosch, D., Boyle, K., & Mykerezi, E. (2015). On consumers' attitudes and willingness to pay for improved drinking water quality and infrastructure. *Water Resources Research*, *51*(1), 47–57. https://doi.org/10.1002/2013WR014934

Taylor, S., & Todd, P. (1995). Decomposition and crossover effects in the theory of planned behavior: A study of consumer adoption intentions. *International Journal of Research in Marketing*, *12*, 137–155.

Taylor, S., & Todd, P. A. (1995). Understanding Information Technology Usage: A Test of Competing Models. *Information Systems Research*, *6*(2), 144–176.

UNEP (2014). *Africa Mountains Atlas.* Nairobi Kenya: United Nations Environemnt Programme (UNEP).

Van Hulst, F. J., & Posthumus, H. (2016). Understanding (non-) adoption of Conservation Agriculture in Kenya using the Reasoned Action Approach. *Land Use Policy*, *56*, 303–314.

Van Noordwijk, M., Coe, R. [Ric], & Sinclair, F. (2016). *Central hypotheses for the third agroforestry paradigm within a common definition.* (Working Paper No. 233). Bogor, Indonesia. https://doi.org/10.5716/WP16079.PDF

Vandreé Julián Palacios Bucheli, & Wolfgang Bokelmann (2017). Agroforestry systems for biodiversity and ecosystem services: the case of the Sibundoy Valley in the Colombian province of Putumayo, *13*(1), 380–397.

Von Carlowitz, P. G. (1989). Agroforestry technologies and fodder production — concepts and examples. *Agroforestry Systems*, *9*(1), 1–16. https://doi.org/10.1007/BF00120151

Wambugu, C., Place, F., & Franzel, S. (2011). Research, development and scaling-up the adoption of fodder shrub innovations in East Africa. *International Journal of Agricultural Sustainability*, *9*(1), 100–109. https://doi.org/10.3763/ijas.2010.0562

Wandji, D. N., Pouomogne, V., Binam, J. N., & Nouaga, R. Y. (2012). Farmer's perception and adoption of new aquaculture technologies in the western highlands of Cameroon. *Tropicultura*, *30*(3), 180–184. Retrieved from http://www.tropicultura.org/text/v30n3/180.pdf

Wauters, E., Bielders, C., Poesen, J., Govers, G., & Mathijs, E. (2010). Adoption of soil conservation practices in Belgium: An examination of the theory of planned behaviour in the agri-environmental domain. *Land Use Policy*, *27*(1), 86–94. https://doi.org/10.1016/j.landusepol.2009.02.009

Whitney, C. W., Tabuti, J. R., Hensel, O., Yeh, C.-H., Gebauer, J., & Luedeling, E. (2017). Homegardens and the future of food and nutrition security in southwest Uganda. *Agricultural Systems*, *154*, 133–144.

Zahid, H., & Din, B. H. (2019). Determinants of Intention to Adopt E-Government Services in Pakistan: An Imperative for Sustainable Development. *Resources*, *8*(128).

CHAPTER THREE

INTRA-HOUSEHOLD DECISION-MAKING IN THE UTILIZATION OF AGROFORESTRY TECHNOLOGIES IN THE EASTERN HIGHLANDS OF UGANDA[2]

Abstract

This chapter examines the intra-household decision-making patterns between male and female decision-makers during the utilization of agroforestry decisions in Uganda's eastern highlands. Quantitative data were collected through a cross-sectional survey of 215 dual-headed households in which both male and female decision-makers were interviewed separately. Qualitative data from focus group discussions were required to inform the cross-sectional survey and explain some quantitative findings. A multiple regression model was applied to determine the factors influencing the decision-making power of females. The study found male decision-makers dominated pre-production, production, and post-production agroforestry decisions. The only decision where females' decision-making power was close to that of their male counterparts was deciding which crops to plant in a particular agroforestry plot. Decision-making power could be associated with males' and females' roles and responsibilities in utilizing agroforestry technologies. The most critical factor influencing female decision-making power was education, labour hours, and male engagement in off-farm income-generating activities. Thus, affirmative action programmes that can, for example, enhance female literacy should be promoted alongside agroforestry interventions.

Keywords: Decision-making, dual-headed households, agroforestry decision, gender, labour hours.

3.1 Introduction

Many agroforestry research and development agencies seek to improve smallholder farmers' livelihoods through new technologies and practices. They target a household as a single agent, assuming that individuals within the household share the same preferences or that the household

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head acts in the family's best interest (Meijer et al., 2015; Rogan, 2013). However, this is contestable, with studies showing that individuals in the household have different preferences 2016; Lusibaet al., 2017; Meijer et al., 2015). As a result, one member's agroforestry decision may not reflect the interests of the other household members (Haider et al., 2018). Moreover, most smallholder farmers, especially in Sub-Saharan Africa, cannot afford to split their land parcels into individually managed plots to cater for household members' individual preferences separately. The organization and management of their fields are often done collectively by all household members through decision-making.

Decision-making is one of the most critical functions undertaken to ration the limiting resources. Central to many household decisions is the idea of decision-making power, which, in the context of this study, reflects one's ability to influence decisions during the utilization of agroforestry technologies (Duflo, 2012; Kabeer, 1999). In many parts of Africa, household heads (usually men) are regarded as principal decision-makers (Kabeer, 1999). The existing social and cultural norms often favour males - consolidating their decision-making power, especially in activities presumed to generate income for the household (Acosta et al., 2019; Kiptot, 2016). However, the growing failure of development interventions to generate anticipated outcomes has led some scholars to question whether males, who often dominate participation, act in their families' best interest. Also, more recognition of females' central role in improving their families' livelihoods suggests that increasing their intra-household decision-making involvement could enhance technological interventions' positive outcomes (Duflo, 2012; Godek & Garcia, 2018; Kabeer, 1999). In this regard, global efforts to improve women's decision-making have become more prevalent. Women's involvement in intra-household decision-making is closely linked to the concept of women's empowerment – the expansion in their ability to make strategic life choices, particularly in contexts where this ability was lacking.

Consequently, gender-responsive approaches have been mainstreamed in the international policy and development agenda. For example, the United Nations' Sustainable Development Goals (SDGs) recognize that improving females' decision-making involvement is crucial to enhance livelihood and boost economic development (UN, 2020). These views have been contextualized into national frameworks and development programs in several nations.

Uganda is one of the few countries in Sub-Saharan Africa where women's influence in decision-making has increased because of affirmative action (Alkire et al., 2013). Policy and development frameworks have now been put in place to accelerate their involvement in agriculture. For example, Uganda's Vision 2040 calls for men and women to be treated as equal partners in development from the household to the national level (The Republic of Uganda, 2013). The National Climate Change Policy encourages both men and women to participate meaningfully in planning, testing and rolling out adaptation and mitigation activities (The Republic of Uganda, 2015). The National Agriculture Sector Strategic Plan (ASSP) 2015/16–2019/20 for Uganda emphasizes training activities in joint decision-making in all community-based development programs (MAAIF, 2016). These frameworks have also been operationalized in sub-national development plans, emphasizing joint decision-making processes between males and females at the household level.

In most dual-headed households, decision-making is a responsibility of husbands and wives (referred to as male and female decision-makers in the context of this study) who may also have different interests concerning household activities (Anderson et al., 2017; Chen & Woolley, 2001; Godek & Garcia, 2018). Their relative decision-making power informs the extent to which these differences are settled. Studies have shown that household decision outcomes vary depending on who influences decision-making. In their research in the Ivory Coast, Duflo and Udry (2004) found out that in years when the females' crop yields were higher than that of their spouses, dual-headed households spent more on food and private goods for females other than male personal goods. Likewise, dual-headed households in South Africa were found to spend more on food than alcohol whenever females garnered larger income shares than their male counterparts (Gummerson & Schneider, 2013). Smith and Chavas (2007) concluded that male-favoured decision-making in Burkinabe households restricted the positive effects of rising income on females' physical well-being. The above studies point to a need for the participation of both male and female decision-makers in decision-making.

Males and females play different roles in agricultural production. The differences in roles may even be broader when about long-term agroforestry technologies. The prevailing view is that agroforestry initiatives are more likely to bring about sustainable and equitable outcomes if designed based on the understanding of intra-household decision-making (Kiptot, 2016; Meijer et al., 2015). Most of the studies that have examined intra-household decision-making have focused on short-term technologies. It is unclear whether these are similar to agroforestry, where decision-making can even break down due to the enterprise's long-term nature. A few studies examining intra-household decision-making in agroforestry are based on data mainly collected from household heads - often biased towards male reports (Rogan, 2013). Besides, these few studies are based on a single aggregated agroforestry decision (e.g. decision to adopt or not to adopt). Such an approach is likely to hide a lot of variability since the interest of males and females in decision-making varies depending on the nature of the decision at stake and social context (Anderson et al., 2017; Bomuhangi et al., 2016; Haider et al., 2018). Therefore, knowledge of male and females' decision-making power in male-female dual-headed households and how it's exercised across agroforestry decisions remains unclear. In this study, dual-headed households are those where males and females stay together in a socially sanctioned engagement based on a sexual relationship. Given the composite nature of agroforestry technologies, the new tasks they introduce, and their multiple outputs, splitting it into sub-activities might improve our understanding of the relative decision-making power between male and female decision-makers concerning specific tasks. This study seeks to determine how decision-making between men and women mediate the use of agroforestry technologies in dual-headed smallholder families. This would help understand relationships of power that might affect decisions to use certain agroforestry technologies. Specifically, this chapter answers three research questions: (1) what agroforestry decisions are made within the dual-headed household? (2) how does decision-making vary between male and female decision-makers during the implementation of the different agroforestry technologies? (3) which socio-demographic factors influence the decision-making power of female decision-makers during the use of agroforestry technologies?

3.2 Theoretical framework

The unitary household model that treats individual household members' preferences as homogenous (Bobonis, 2009; Quisumbing & Maluccio, 2003) has been used in many studies that examine intra-household decisions. Under this framework, the attention is on the household heads who are assumed to be selfless for other household members' well-being. However, the unitary household model does not consider decision-making processes and underscores the individual factors that influence outcomes across various decisions (Duflo & Udry, 2004; Richards et al., 2013). This chapter draws from the cooperative bargaining model (Marchant, 1997; Stahl Ingolf,

1972) to examine intra-household agroforestry decisions among dual-headed households in Uganda's eastern highlands. The model posits that decision-making in dual-headed households is negotiated directly between spouses (male and female decision-makers). Decisions that emerge reflect each one's influence within the household. At the heart of this model is the 'decision-making process' through which male and female decision-makers on their own try to reach an agreement on a particular course of action (Gummerson & Schneider, 2013; Stahl Ingolf, 1972). Decisions are perceived differently by both males and females and have to be negotiated (Anderson et al., 2017). In the context of this study, it is conceptualized that the relative decision-making power informs agroforestry decisions reached in the dual-headed households, which in turn is informed by their roles and responsibilities and individual socio-demographic characteristics (Figure 3.1).

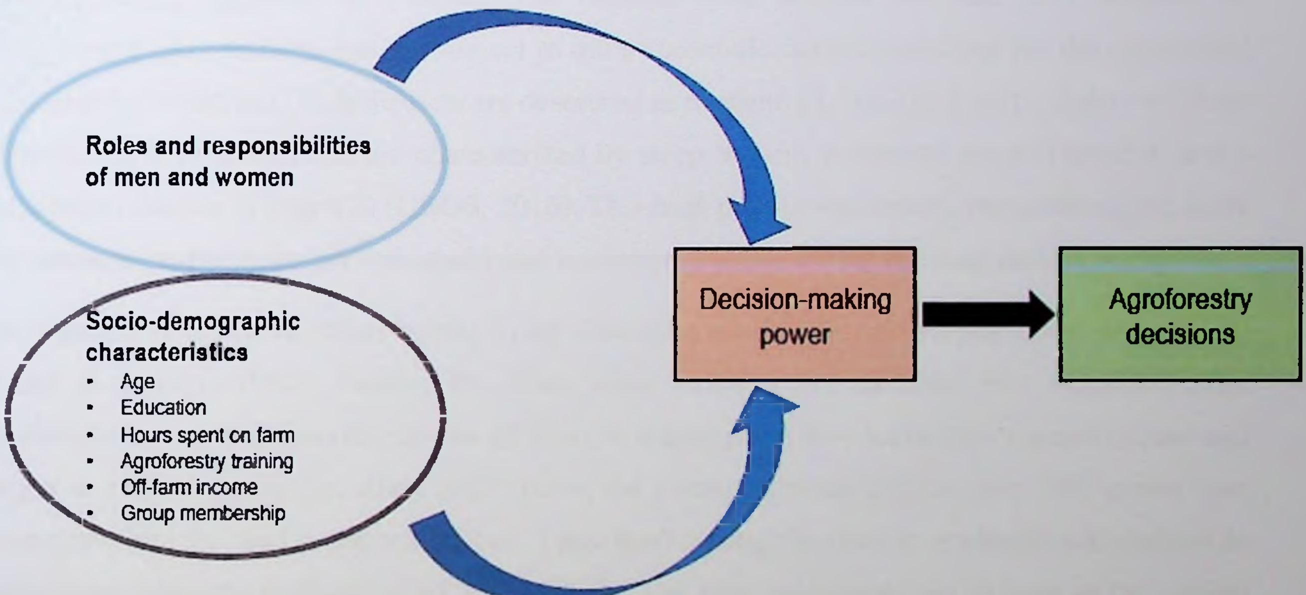

Figure 3.1: Conceptual framework of the study (Source: own elaboration)

Given that this study was carried out in a patriarchal community, where decision-making is by default a privilege of the males, particular focus was given to the influence of females in decision-making because, by default, they are the most constrained in the pursuit of livelihood portfolios (Lawless et al., 2019). Socio-demographic attributes such as age, education, and farm labour hours, agroforestry training, off-farm income, group membership, duration in marriage, and the number of children shared are vital determinants of decision-making power (Ashraf, 2009; Bertocchi et al., 2014; Bradshaw, 2013; Doss, 2013). Simultaneously, decision-making power seems to be conditioned by the segregation of roles and responsibilities between male and female decision-makers in the household (Gummerson & Schneider, 2013; Lawless et al., 2019; Sow, 2010). This study assumed that male and female decision-makers in the dual-headed household do not evoke non-cooperative threat points such as violence and divorce (Seebens, 2011). Both husband and wife were treated as interdependent – exercising their decision-making power while leaning more to the family interests than their utility frontiers.

3.3 Methodology

3.3.1 Description of the study area

The research was carried-out in Manafwa (00°55'N 34°17'E) and Namisindwa (00°49'N 34°23'E) in the eastern highlands of Uganda. The districts were selected because they focused on agroforestry interventions that are subject to intra-household decision-making for the anticipated outcome to be realized. Both districts are described as medium (1,164-1625 m) to high (>1625 m) altitudes (UNDP, 2013) and are characterized by steep terrain, a bimodal rainfall pattern, and a population density of over 900 (UBOS, 2016). This high population density tremendously reduces the average land acreage per household and increases pressure on the existing natural resources.

Most people in the two districts belong to the Gisu tribe who subscribe to a patrilineal descent (De Graaf & Robert, 1994). Among the Gisu, male children are initiated into manhood after circumcision, which occurs as early as 15 years, at which point they leave their parental house and begin to live independently. Also, at this point, the parents allocate land to their 'full-grown' son to prepare him for family responsibilities. Thus, land among the Gisu is gradually sub-divided as more sons transform into adulthood in the family. The girls are married off as soon as they finish or drop out of school.

Agriculture is the primary source of livelihood, with coffee, beans, maize, bananas, vegetables (onions, cabbage, tomato), and fruits being the major enterprises (Oduol et al., 2016). Declining land productivity has become more pronounced, especially among smallholder farmers, due to soil erosion, deforestation, and intensive cultivation of steep slopes. Environmental impacts such as landslides, floods, drought, pests and diseases are rampant in the districts, further leading to reduced land productivity (Bomuhangi et al., 2016; Jiang, Bamutaze, & Pilesjö, 2014; Mbogga, 2013; Mubangizi et al., 2017). Research and development agencies have promoted innovative agroforestry technologies to enhance farm productivity within the existing intensively managed banana-coffee agroforestry system. However, such interventions also paid limited attention to intra-household decision-making, leading to success or failure to realize the anticipated outcomes (Doss, 2013).

3.3.2 Research design

A cross-sectional survey was conducted in April 2019 to collect data from male and female decision-makers (husbands and wives) in dual-headed households regarding their decision-making power on critical agroforestry decisions. Focus group discussions were carried out in two phases. First, to 1) identify the critical areas where the agroforestry decisions are made within the dual-headed households, which were subjected to respondents during the cross-sectional survey; and 2) to determine the variation in roles and responsibilities for male and female decision-makers during the implementation of agroforestry. Second, after the survey to support and add meaning to some of the quantitative findings.

3.3.3 Sampling and sample selection

The study population was defined as all dual-headed households in the targeted sub-counties implementing agroforestry for the survey. A list of 492 dual-headed households implementing agroforestry generated with agricultural officers and a few extension staff for development agencies operating in the targeted sub-counties constituted a sampling frame. A sample of 215 dual-headed households was randomly obtained following Krejcie and Morgan (1970), resulting in 430 respondents.

Non-probability sampling was employed during the selection of participants for the focus groups. A total of 6 focus group discussions averaging nine participants were conducted. The focus group discussions involved 57 participants (30 males and 27 females) who were purposively selected from the dual-headed households to capture a diversity of decision-making patterns related to agroforestry.

3.3.4 Data collection

The first phase of data collection involved four focus group discussions focusing on identifying the roles and responsibilities of male and female decision-makers in agroforestry and the critical areas where agroforestry decisions are made within the dual-headed household. This was followed by a survey where a semi-structured questionnaire was used to elicit data from 215 dual-headed households. For each dual-headed household, husband and wife (here referred to as male and female decision-maker respectively) were interviewed separately to reduce response bias that could arise from cultural norms and expectations (Anderson et al., 2017). The survey questionnaire collected data on socio-demographic characteristics and decision-making power regarding the critical agroforestry decisions identified during the earlier focus group discussions. Questions on socio-demographic characteristics focused on age, years of education, the number of labour hours spent working on the farm daily, training attained in agroforestry, off-farm income, and group membership. Following Anderson et al. (2017), I adapted a scale of 0 to 10 for each decision-maker to score their decision-making power in a given agroforestry decision (Table 3.1). By allocating him/herself a given score using this scale, the decision-maker indirectly scored their counterpart. If, for example, the male decision-maker allocated himself 6, he would be indirectly giving 4 to the female counterpart.

Table 3.1: Description of the scale used to score decision-making power

Score	Description
10:0	A decision-maker holds all the decision-making power. They do not have to inform their counterpart before or after the decision
9:1	A decision-maker informs their counterpart about the decision after it has been taken
8:2	Informs their counterpart about the decision before its execution
7:3	A decision-maker informs the other before the execution of the decision to hear their ideas, but their arguments are rarely considered
6:4	A decision-maker considers alternative ideas, but they have the final say
5:5	Both male and female decision-makers participate equally in the decision-making process and agree on a course of action

Finally, two focus group discussions were conducted to generate data for explaining some of the quantitative findings. FGDs were held separately for both men and women to provide spaces where each group could freely express their ideas without bias. Participants were asked why they felt a particular decision fell predominantly to male or female decision-makers. Follow-up questions were used to generate more information about emerging issues.

3.3.5 Analysis

The quantitative survey data were analyzed using STATA version 13.0 to generate descriptive and inferential statistics. Descriptive statistics, including means and percentages, described the sample. To examine the variation in decision-making power between male and female decision-makers across the different agroforestry technologies, an independent sample t-test was used. Multiple linear regression was used to determine the socio-demographic factors influencing females' decision-making power. The model is specified as:

$$F_p = \beta_0 + \beta_1 h_1 + \beta_2 h_2 + \ldots + \beta_n h_n + \varepsilon$$

Where:

- F_p = Overall decision-making power of female decision-maker
- β_0 = Coefficient of the constant term (intercept)
- $h_1, h_2, \ldots, h_n$ = Socio-demographic factors of the female decision-maker
- $\beta_1, \beta_2 \ldots \beta_n$ = regression coefficients; ε = random error

Table 3.2. Description of explanatory variables used in the models

Variable	Variable description	Variable measurement	A priori sign	
			Accord	Discord
1. Wife specific characteristics				
Age	Age of the female decision-maker	Continuous	+	+
Education	Number of years spent by the female decision-maker in school	Continuous	+	+
Farm labour hours	Number of hours a female decision-maker spends on the farm daily	Continuous	+	+
Land size	Total land owned by the household in acres	Continuous	+	+
Group membership	Whether the female decision-maker was a member of a farmer organization	Categorical	+	+
Training in agroforestry	Whether the female decision-maker has ever trained in agroforestry	Categorical	+	+
Female involved in off-farm activities	Wife participates in off-farm income-generating activities	Categorical	+	+

Male involved in off-farm activities	Husband involved in off-farm income-generating activities	Categorical	+	+
Number of children	Number of children shared between male and female decision-makers	Continuous	±	±
Duration in marriage	Number of years both male and female have spent living together	Continuous	+	+

Table 3.2 shows how the explanatory variables included in the model were operationalized and their hypothesized influence on decision-making. Qualitative data from focus group discussions were analyzed using content analysis. The detailed explanations gained from FGDs (including anecdotal evidence) were used to elaborate on the survey's quantitative findings.

3.4 Results and discussions

3.4.1 Description of the respondents

The summary statistics of the respondents involved in the study are presented in Table 3.3. There were significant differences between male and female decision-makers regarding age, education, hours spent on-farm and off-farm income. The age of the respondents averaged 49 and 42 years for male and female decision-makers, respectively. The average number of years spent in school was eight years for males and six years for females. Males spent less time on the farm (4.8 hours) than their female counterparts (5.6 hours) because they were more involved in other off-farm activities such as brick-making, shop-keeping, carpentry and Bodaboda. Generally, wives spent significantly more time working on the farm than their husbands. About 52% of the males had off-farm income compared to 33% of the females.

Table 3.3: Characteristics of the sample

Variable	Male (n=215)	Female (n=215)	T-test/Pearson's chi-square (X^2)
Age in years	48.84	42.24	5.343***
Education in years	7.66	6.23	4.032***
Hours spent on the farm	4.76	5.55	1.872**
Training in agroforestry	48.5%	48.0%	0.010
Off-farm income	51.5%	33.0%	2.899***
Membership to farmer group	28.3%	31.0%	0.352

*, ** and *** indicate statistical significance level at 10%, 5% and 1% respectively

3.4.2 Roles and responsibilities of male and female decision-makers in agroforestry

Male and female decision-makers were involved in all the agroforestry activities but to a varying extent (Table 3.4). Male decision-makers dominated 60% of the agroforestry activities, including attending agroforestry training, land preparation, planting tree seedlings, pruning, thinning, and marketing the tree products. On the other hand, female decision-makers dominated only 30% of the agroforestry activities, including integrating crop enterprises, weeding, and protecting trees against grazing animals. Although harvesting tree products is mainly done jointly, it was later explained during the focus group discussions that women are primarily involved in harvesting household products such as firewood, medicine, and fruits. At the same time, men harvest products like timber and poles for selling. Women mainly harvest the twigs, branches, leaves while males dominate the harvesting of trunks converted to commercial products like timber. These roles and responsibilities in agroforestry are positively linked to the social norms, fairly clear-cut among the Gisu.

On the other hand, females were expected to fulfil household roles – they clean, cook, care for the children and livestock, and provide household food security through farming. The males (usually the household heads) are characteristically in charge of generating income through agriculture or other off-farm activities. The type of crops men and women grow can also differ according to these social norms. Women were more associated with food crops such as beans, cassava, sweet potato to secure food. In contrast, cash crops such as coffee and other high-value crops like tomatoes belong to men. Women can only generate income by selling the surplus of the food crops that their male counterparts are not closely monitoring.

Table 3.4: Roles and responsibilities of male and female decision-makers in agroforestry

Activity	Husband (%)	Wife (%)	Joint (%)
Attending agroforestry training	70.0	21.4	8.6
Preparing land	76.0	19.8	4.2
Planting of tree seedlings	64.4	12.1	23.5
Integrating crop enterprises	10.3	51.7	38.0
Weeding agroforestry plot	13.0	53.3	33.7
Pruning trees in the agroforestry plot	74.1	12.3	13.6
Thinning trees in the agroforestry plot	80.2	7.5	12.3
Protecting trees against grazing animals	23.7	55.1	21.2
Harvesting of tree products	32.1	18.8	49.1
Marketing of the products	55.4	5.1	39.5

NB: the percentage scores were generated from participants in the FGDs (n=36)

3.4.3 Agroforestry decisions made within a dual-headed household

During the focus group discussions, participants generated a list of agroforestry decisions that smallholder households implement more often. The decisions were categorized according to their nature and time horizon into pre-production, production and post-production decisions (Figure 3.2). The pre-production decisions were regarded as key in unlocking barriers to the implementation of agroforestry. For long-term agroforestry, decisions made at this stage can have a long-term positive or negative implication throughout future production cycles (Reynolds et al., 2015). Therefore, the decision to attend agroforestry training is critical as it eventually translates into how technologies are implemented on the farm. This may also inform which tree species to plant on the farm. Production decisions were made on the agroforestry plot, including management aspects of the tree component. The smallholder farming household's primary aim is to maximize the farm's productivity, taking food and income security into account. In this sense, farmers made decisions on the trees' location, crop enterprises to integrate on the farm and tree management options such as thinning and pruning (both canopy and crown) to optimize tree-crop interactions. The decision about where to plant trees on the farm was critical; it determined the success of agroforestry and informed the management options to be undertaken. Post-production decisions aimed to generate tree products that could be used domestically or sold to generate income. They included decisions on the type of products to harvest given the multiple needs of the farming household, the variety of products to sell, and how to spend the income generated from tree products.

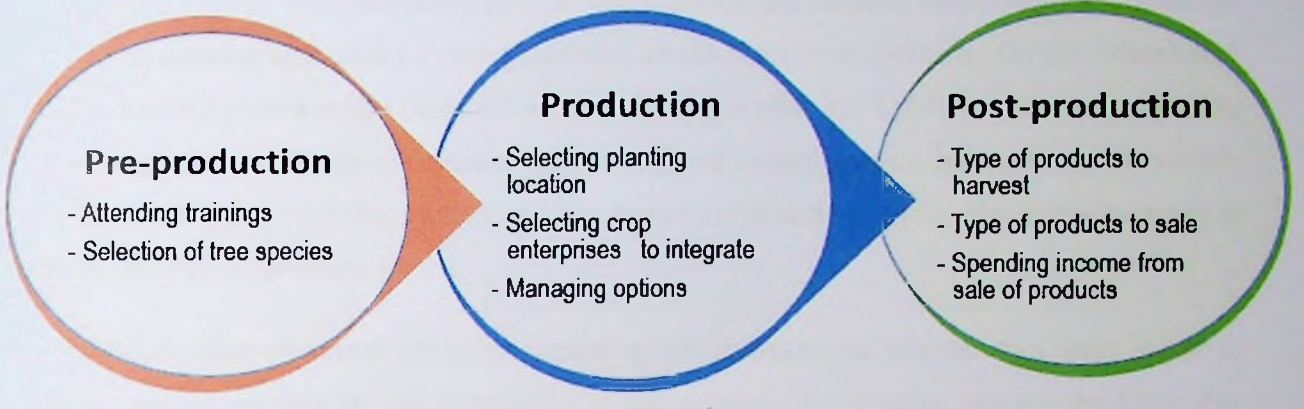

Figure 3.2: Characterization of agroforestry decisions among smallholder households

3.4.4 Decision-making power of male and female decision-makers

Table 3.5 highlights the mean scores of decision-making powers claimed by male and female decision-makers across the eight agroforestry decisions. Generally, males dominate decision-making for seven out of eight decisions. One decision where females had almost the same decision-making power as their male counterparts were on the crop enterprises to incorporate in the agroforestry plot. Results of focus group discussions revealed that crop enterprises that female decision-makers often included in the agroforestry plot were predominantly annual such as beans, maize, cassava and potatoes, and mainly used to secure household food requirements. The decision-making power of wives was highest for decisions concerning which enterprises to incorporate in the agroforestry plot. It's associated with their household role of providing food to the household members. Crop enterprises, especially of subsistence nature, are linked to the females' role of securing food for their household, as affirmed by one of the female decision-makers during the FGDs: *"My husband is always interested in income-generating enterprises. As a woman, it is my responsibility to grow enough food to feed the family. Thus, I'm involved in most of the decisions regarding food security crops to integrate on the farm"*. These findings are supported by the existing literature showing that women tend to dominate decisions linked to their roles and social norms – mainly activities such as food preparation and firewood collection

(Bomuhangi et al., 2016; Enete & Amusa, 2010; Meijer et al., 2015). Females' decision-making power was lowest for deciding which tree products to sell to the market. This demonstrates their continued disempowerment in decisions related to household income (Lusiba et al., 2017). Further, decisions on which products to sell are linked to market information, a privilege of male decision-makers given their mobility. Female decision-makers contend with multiple household roles such as cooking and taking care of children, which limit their mobility. On the other hand, Males visit trading centres for their social errands and search for off-farm income-generating activities and are more likely to interact with traders and access market information. Therefore, female decision-makers are less likely to access market information, which disempowers them to decide on the type of products to sell.

From the FGDs, men often took decisions regarding tree management because they were linked to their roles and responsibilities and entrenched in the existing social norms among the Gisu. For example, pollarding and pruning often involve climbing trees. Climbing trees is culturally regarded as an indecent practice by girls and women among the Gisu because it exposes their legs above their knees. This is supported by previous studies that linked household decision-making to cultural and social norms (Bomuhang et al., 2016; Lusiba et al., 2017).

Table 3.5: Overall decision-making power of male and female decision-makers

Decision category	Agroforestry decision	Mean score (males)	Mean score (females)	T-test
Pre-production	Attending training	6.55	3.65	14.367***
	Selecting tree species	7.07	3.25	20.192***
Production	Selecting planting location	7.08	3.44	18.669***
	Selecting crop enterprises	5.17	5.12	0.276
	Management options	6.98	3.77	17.485***
Post-production	Type of products to harvest	7.24	3.02	22.372***
	Type of products to sale	7.41	2.96	22.226***
	Use of income	6.25	3.89	14.400***

*, ** and *** indicate statistical significance level at 10%, 5% and 1% respectively

Table 3.6 shows the decision-making power variation between male and female decision-makers across the main agroforestry technologies (boundary planting, intercropping and woodlot) in the eastern highlands. Even across the implementation of different agroforestry technologies, males predominantly made decisions from pre-production to post-production. Studies show that long-term enterprises like coffee and cocoa are primarily associated with men because of their commercial value (Howland et al., 2020; Lyon et al., 2019). Trees are not any different from such long-term enterprises. Although they can give other benefits along the way, trees are more evaluated for their commercial value, which falls in the domain of male decision-makers. As default landowners, men don't want to lose the commercial value of selling tree products such as poles and timber.

Table 3.6: Variation of male and female decision-making power across agroforestry technologies

Decision category	Agroforestry decision	t-test (Boundary)	t-test (Intercropping)	t-test (Woodlot)
Pre-production	Attending training	6.515***	13.165***	3.522***
	Selecting tree species	5.794***	18.607***	7.351***
Production	Selecting planting location	5.735***	16.845***	7.048***
	Selecting crop enterprises	0.159	0.917	-0.852
	Management options	5.481***	16.043***	5.692***
Post-production	Type of products to harvest	7.987***	20.227***	7.080****
	Type of products to sale	8.907***	18.473***	9.046***
	Use of income	4.997***	12.457***	5.742***

*, ** and *** indicate statistical significance level at 10%, 5% and 1% respectively

3.4.5 Factors influencing females' decision-making power

Before undertaking a multiple regression model, data reduction procedures for improving the model's accuracy were done. A Pearson correlation matrix was generated (Table 3.7) to remove highly correlated variables. If two variables were significantly correlated, their mean absolute correlations were compared, and the variable with the largest mean was removed to improve the model's accuracy (Weisberg, 2002). This helped to remove highly correlated variables. Age of the female decision-maker, total livestock units, wife involvement in off-farm income-generating activities, number of children and agroforestry training attendance were dropped in our model. A multiple regression model was run to understand the factors relevant in enhancing females' decision-making power in agroforestry. The R-square value was of 0.642 suggests that approximately 64% of the variation observed in female decision-making power score is explained by the predictor variables (Table 3.8). The adjusted R^2 of 0.392, an unbiased estimator for the population R-square, is above 0.25 – a threshold considered adequate in predicting social science phenomena (Kutner et al., 2005). This is because social science phenomena are highly complex, and thus, it is challenging to develop a model that captures all the factors that influence an outcome (Von Eye & Christof, 1998). The F-value was significant at $P<0.01$, rejecting the null hypothesis that our entire regression model has a population R of zero.

Table 3.7: Pearson correlations among independent variables

	1	2	3	4	5	6	7	8	9	10	11
1. Age of the female decision-maker	1										
2. Years spent in school	-0.277**	1									
3. Hours spent farming	-0.002	-0.056	1								
4. Total livestock units	0.167*	0.021	0.077	1							
5. Duration in marriage	0.129	-0.124	-0.021	0.037	1						
6. Wife involvement in off-farm income activities	0.045	-0.061	-0.010	-0.035	0.048	1					
7. Membership in farmers' organisations	0.039	-0.138	0.104	0.057	0.078	0.179*	1				
8. Male involvement in off-income activities	-0.193**	0.300**	-0.018	-0.034	-0.029	-0.184**	-0.038	1			
9. Number of children	0.069	-0.116	0.056	0.043	0.690**	0.120	0.065	0.062	1		
10. Size of land owned	0.128	0.103	0.087	0.295**	0.094	-0.100	0.100	0.000	0.041	1	
11. Agroforestry training	-0.003	-0.169*	-0.084	0.075	0.160*	0.115	0.135	-0.134	0.107	0.033	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3.8: Model summary of the multiple regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F-value	Sig. F change
1	0.454[a]	0.642	0.392	1.067	3.449	0.004

Years spent in school, and males' involvement in off-farm activities were the most critical factors associated with female decision-making power ($P<0.05$) (Table 3.8). Similar to what was reported by Sell and Minot (2018) and Okanya et al. (2021), the current study's findings also found a positive relationship between females' decision-making power and education level. For each one-year increase in school time, the decision-making power of a female decision-maker increases by 0.0.691, keeping all other factors constant. Highly educated females are expected to make good and well-informed decisions for the family's wellbeing (Anderson et al., 2017). The more females become educated, the more confident they articulate their ideas. Several studies have shown education to be a key component of women's decision-making power within the household (Becker et al., 2006; Colfer et al., 2015; Peterman et al., 2015). This reflects the possibility that increasing a female's education may allow her to participate jointly with her male decision-maker in a household in decisions. This result implies that development efforts should focus on increasing girls' school enrollment at all levels.

Females' membership in farmers' organisations increases their decision-making power by 0.142 when all other independent variables are held constant. It's possible that the positive influence of membership to farmers' organisations to females' decision-making power observed in the current study could be attributed to the skills development trainings received by women from development organisations. Female decision-makers assume more responsibility for managing components on the farm when they are members of farmers' organisations. Thus, they become more involved in some of the decisions, as one of the participants explained during the focus group discussion: "*My husband allowed me to join a farmers' group. We received several trainings in different disciplines such as leadership and agroforestry. He agrees with many of my suggestions on what we need to do on the farm*".

Women in Uganda are increasingly becoming members of farmers' organisations like village savings and credit associations. They often receive training in financial literacy, record-keeping, agroforestry, confidence building, leadership, among others (Mukhooli, 2015). Membership to farmer organisations in Uganda has been reported to increase women's decision-making power within the household and increase uptake of better farming practices and economic well-being (Lecoutere, 2017). My finding is in line with that of Sell and Minot (2018), who also reported that membership to local organisations was highly correlated to high levels of decision-making by women.

Table 3.9: Determinants of females' decision-making power

Model	Unstandardized coefficients		Standardized coefficients	t-value	Sig.
	B	Std. error	Beta		
Constant	112.817	40.513		35.495	0.000
Year spent in school	0.691	0.326	0.297	2.611	0.006*
Farm labour hours	0.794	0342	0.331	1.850	0.102
Membership in farmers' organisations	0.342	0.192	0.099	1.825	0.008*
Male involvement in off-farm activities	0.424	0.170	0.097	1.774	0.040*
Duration in marriage	0.101	0.067	0.069	0.134	0.894
Land size owned by the household	0.218	0.088	0.070	1.285	0.076

*Significant at P<0.05

As males (husbands) engage in off-farm activities, females' decision-making power increases by 0.424. This is possible because the extra responsibilities off-farm force their male counterparts to delegate some decision roles. When males engage in off-farm income-generating activities, it gives their female counterparts room to transit their ideas onto the farm (Graziella et al., 2014). When male counterparts diversify their income base off-farm, females take up additional responsibility in decision-making on the farm. Male involvement in off-farm activities is an opportunity in disguise for their female counterparts to have a grip on the farm activities, increasing their decision-making power. This suggests that the expansion of men's portfolio of economic activities outside the farm can have a marginal effect of empowering their female counterparts in on-farm decision-making, particularly in the use of agroforestry technologies.

Other studies have reported factors such as the contribution of the wife to household expenditure, religion and ethnicity to influence decision-making at household levels, with men making almost all the decisions in highly religious families (Maligalig et al., 2019; Quaye et al., 2016; Sell and Minot, 2018). However, the current study didn't examine the influence of females' contribution to household expenditure, religion, and ethnicity on decision-making. Future studies can look at these and more socio-economic and cultural factors.

3.5 Conclusions

Within the dual-headed households, male decision-makers dominate pre-production, production, and post-production decisions during agroforestry implementation regardless of the implemented agroforestry technology. The only time females had decision-making power close to that of males was in decisions concerning crop enterprises to integrate into the agroforestry plot, which was linked to their social role of securing food for the household. The dominance of males in agroforestry decisions may be counter-productive. When women decide to abscond from their roles (integrating crops, weeding and protecting tree seedlings against grazing animals) because agroforestry decisions are not favourable to food production, agroforestry's anticipated outcomes may not be realized. It also implies that agroforestry interventions targeting females alone in dual-headed households risk failure unless male decision-makers favour them.

The study finds that female decision-makers' influence in decision-making increases as their education and membership to farmers' organisations increase and their spouses engage in off-farm income-generating activities. As men take up other off-farm roles, women take up some on-farm activities and decision-making. As jobs become more readily available in urban and peri-urban areas, men are more likely to be engaged in off-farm activities because of their mobility, thereby allowing their female counterparts to make decisions on-farm. Also, affirmative action programmes that can, for example, enhance female literacy should be promoted alongside agroforestry interventions. Such affirmative action programmes could include adult literacy programmes for women tailored to suit their needs and policies to reduce barriers to a girl child's primary and school education.

Data were obtained through self-reports, and such responses are subject to recall and reporting bias. This study also used proxy responses which are liable to face certain biases, especially when it comes to one spouse estimating the levels of other's involvement in decision-making (Alkire et al., 2013). Using proxies could have caused some biased responses since some men underestimate the true extent of their wives' domestic and agricultural activities (Malena, 1994). We also acknowledge that other socio-economic and cultural factors associated with the wife's authority should be investigated in future studies.

References

Acosta, M., van Wessel, M., van Bommel, S., Ampaire, E. L., Twyman, J., Jassogne, L., & Feindt, P. H. (2019). What does it Mean to Make a 'Joint' Decision? Unpacking Intra-household Decision Making in Agriculture: Implications for Policy and Practice. *The Journal of Development Studies*, 1–21.

Alkire, S., Meinzen-Dick, R. S., Peterman, A., Quisumbing, A. R., Seymour, G., & Vaz, A. (2013). The Women's Empowerment in Agriculture Index. *World Development*, *52*, 71–79. https://doi.org/10.2139/ssrn.2197300

Anderson, C. L., Reynolds, T. W., & Gugerty, K. M. (2017). Husband and Wife Perspectives on Farm Household Decision-making Authority and Evidence on Intra-household Accord in Rural Tanzania. *World Development*, *90*, 169–183.

Ashraf, N. (2009). Spousal Control and Intra-Household Decision Making: An Experimental Study in the Philippines. *American Economic Review*, *99*(4), 1245–1277.

Becker, S., Fonseca-Becker, F., & Schenck-Yglesias, C. (2006). Husbands' and wives' reports of women's decision-making power in Western Guatemala and their effects on preventive health behaviors. *Social Science & Medicine*, *62*(9), 2313–2326. https://doi.org/10.1016/j.socscimed.2005.10.006

Bertocchi, G., Brunetti, M., & Torricelli, C. (2014). Who holds the purse strings within the household? The determinants of intra-family decision making. *Journal of Economic Behaviour and Organization*, *101*, 65–86.

Bobonis, G. J. (2009). Is the Allocation of Resources within the Household Efficient? New Evidence from a Randomized Experiment. *The World Bank Research Observer*, *117*(3), 453–503. https://doi.org/10.1086/600076

Bomuhangi, A., Nabanoga, G., Namaalwa, J. J., Jacobson, M. G., Abwoli, B., & Wich, S. (2016). Local communities' perceptions of climate variability in the Mt. Elgon region, eastern Uganda. *Cogent Environmental Science*, *2*(1), 1168276. https://doi.org/10.1080/23311843.2016.1168276

Bomuhangi, A., Nabanoga, G. N., Namaalwa, J., Jacobson, M., & Gombya-Ssembajjwe, W. (2016). Gendered decision making and adaptation to climate change in Mt. Elgon Region, Eastern Uganda. *International Research Journal of Environmental Sciences and Studies*, *1*(1), 1–23.

Bradshaw, S. (2013). Women's decision-making in rural and urban households in Nicaragua: the influence of income and ideology. *Environment and Urbanization*, *25*(1), 81–94.

C. Leigh Anderson, Travis W. Reynolds, & Mary Kay Gugerty (2017). Husband and Wife Perspectives on Farm Household Decision-making Authority and Evidence on Intra-household Accord in Rural Tanzania. *World Development*, *90*, 169–183.

Chen, Z., & Woolley, F. (2001). A Cournot-Nash Model of Family Decision Making *The Economic Journal*, *111*(474), 722–748. https://doi.org/10.1111/1468-0297.00657

Colfer, C. J. P., Achdiawan, R., Roshetko, J. M., Mulyoutami, E., Yuliani, E. L., Mulyana, A., . . . Erni (2015). The Balance of Power in Household Decision-Making: Encouraging News on Gender in Southern Sulawesi. *World Development*, *76*, 147–164. https://doi.org/10.1016/j.worlddev.2015.06.008

De Graaf, W., & Robert, M. (1994). *Sociogenesis reexamined.* New York: Springer.

Doss, C. (2013). Intrahousehold Bargaining and Resource Allocation in Developing Countries. *The World Bank Research Observer*, *28*(1), 52–78. https://doi.org/10.1093/wbro/lkt001

Duflo, E. (2012). Women Empowerment and Economic Development. *Journal of Economic Literature*, *50*(4), 1051–1079.

Duflo, E., & Udry, C. (2004). *Intrahousehold Resource Allocation in Cote d'Ivoire: Social Norms, Separate Accounts and Consumption Choices* (Working Paper 10498). Cambridge, MA. https://doi.org/10.3386/w10498

Enete, A. A., & Amusa, T. A. (2010). Contribution of Men and Women to Farming Decisions in Cocoa Based Agroforestry Households of Ekiti State, Nigeria. *Tropicultura*, *28*(2), 77–83.

Godek, W., & Garcia, M. A. (Eds.) (2018). *Unpacking Intra-Household Decision-Making on Smallholder Farms in Colombia and Nicaragua to Foster Climate Change Adaptation*: International Centre for Tropical Agriculture.

Graziella Bertocchi, Marianna Brunetti, & Costanza Torricelli (2014). Who holds the purse strings within the household? The determinants of intra-family decision making, *101*, 65–86.

Gummerson, E., & Schneider, D. (2013). Eat, Drink, Man, Woman: Gender, Income Share and Household Expenditure in South Africa. *Social Forces*, *91*(3), 813–836.

Haider, H., Smale, M., & Theriault, V. (2018). Intensification and intrahousehold decisions: Fertilizer adoption in Burkina Faso. *World Development*, *105*, 310–320.

Howland, O., Brockington, D., & Noe, C. (2020). Women's Tears or Coffee Blight? Gender Dynamics and Livelihood Strategies in Contexts of Agricultural Transformation in Tanzania. *Journal of Political Economy*, *9*(2), 171–196.

Jiang, B., Bamutaze, Y., & Pilesjö, P. (2014). Climate change and land degradation in Africa: a case study in the Mount Elgon region, Uganda. *Geo-Spatial Information Science*, *17*(1), 39–53. https://doi.org/10.1080/10095020.2014.889271

Kabeer, N. (1999). *The conditions and consequences of choice: reflections on the measurement of women's empowerment* (UNRISD Discussion Paper No. 108). Geneva, Switzerland. Retrieved from United Nations Research Institute for Social Development website: https://www.files.ethz.ch/isn/28994/dp108.pdf

Kiptot, E. (2016). Gender roles, responsibilities, and spaces: implications for agroforestry research and development in Africa. *International Forestry Review*, *17*(S4), 11–21.

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, *30*, 607–610.

Kutner, M. H., Nachtsheim, C. J., Neter, J., & Li, W. (2005). *Applied linear statistical models*. New York.

Lawless, S., Cohen, P., McDougall, C., Orirana, G., Siota, F., & Doyle, K. (2019). Gender norms and relations: Implications for agency in coastal livelihoods. *Maritime Studies*, *18*(3), 347–358. https://doi.org/10.1007/s40152-019-00147-0

Lecoutere, E. (2017). The impact of agricultural co-operatives on women's empowerment: evidence from Uganda. J. Co-op. Organ. Manag. 5, 14–27. doi: 10.1016/j.jcom.2017.03.001

Lusiba, G. S., Kibwika, P., & Kyazze, F. B. [Florence Birungi] (2017). Intra-household gender division of labour and decision-making on rice postharvest handling practices: A case of Eastern Uganda. *Cogent Social Sciences*, *3*, 1296323.

Lyon, S., Mutersbaugh, T., & Worthen, H. (2019). Constructing the female coffee farmer: Do corporate smart-economic initiatives promote gender equity within agricultural value chains? *Economic Anthropology*, *6*(1), 34–47. https://doi.org/10.1002/sea2.12129

MAAIF (2016). *Agriculture sector strategic plan 2015/16-2019/20*. Entebbe, Uganda. Retrieved from Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) website: http://agriculture.go.ug/wp-content/uploads/2019/05/Agriculture-Sector-Strategic-Plan-ASSP.pdf

Malena, C. (1994). Gender Issues in Integrated Pest Management in African Agriculture. Chantham: Natural Resources Institute.

Maligalig, R., Demont, M., Umberger, W. J., & Peralta, A. (2019). Off-farm employment increases women's empowerment: Evidence from rice farms in the Philippines. *Journal of Rural Studies*, *71*, 62–72. https://doi.org/10.1016/j.jrurstud.2019.09.002

Marchant, M. A. (1997). Bargaining Models for Farm Household Decision Making: Discussion. *American Journal of Agricultural Economics*, *79*(2), 602–604. https://doi.org/10.2307/1244158

Mbogga, M. (2013). *Climate profiles and climate change vulnerability assessment for the Mbale region of Uganda* (UNDP Consultancy report). Kampala, Uganda. Retrieved from https://www.adaptation-undp.org/sites/default/files/downloads/tacc_mbale_climate_profile_and_cc_vulnerability_assessment_report_final.pdf

Meijer, S. S., Sileshi, G. W., Kundhlande, G., Catacutan, D., & Nieuwenhuis, M. (2015). The role of gender and kinship structure in household decision-making for agriculture and tree planting in Malawi. *Journal of Gender, Agriculture and Food Security*, *1*(1), 54–76.

Mubangizi, N., Kyazze, F. B. [Florence B.], & Mukwaya, P. I. (2017). Smallholder farmers' perception and adaptation to rainfall variability in Mt. Elgon region, Eastern Uganda. *International Journal of Agricultural Extension*, *5*(3), 103–117.

Mukhooli, C. (2015). Impact of Microedit Programs on Women's Empowerment in East Africa (Uganda, Kenya, and Tanzania). Murdoch, WA: Murdoch University.

Oduol, J., Tanui, J., Isubikalu, P., Buyinza, J., Kiptot, E., Okia, C., & Kyazze, F. (2016). *Scoping study to generate insights into potential value chains and institutional arrangements in Manafwa district, Uganda*. Retrieved from http://www.worldagroforestry.org/sites/agroforestry/files/out-put/attachments/Manafwa%20Uganda%20%20Scoping%20Study%20Report%20%20July%202016.pdf

Okonya, J. S., Mudege, N. N., Nyaga, J. N., & Jogo, W. (2021). Determinants of women's decision-making power in pest and disease management: Evidence from Uganda. Frontiers in Sustainable Food Systems, 5, 252.

Quaye,W., Dowuona, S., Okai,M., and Dziedzoave, N. (2016). Gender dimensions of decision-making on production assets and challenges facing women. Dev. Pract. 26, 77–90. doi: 10.1080/09614524.2016.1112364

Peterman, A., Schwab, B., Roy, S., Hidrobo, M., & Gilligan, D. (2015). *Measuring Women's Decision-making: Indicator Choice and Survey Design Experiments from Cash and Food Transfer Evaluations in Ecuador, Uganda, and Yemen* (IFPRI Discussion Paper No. 1453). Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2685232

Quisumbing, A. R., & Maluccio, J. A. (2003). Resources at Marriage and Intrahousehold Allocation: Evidence from Bangladesh, Ethiopia, Indonesia, and South Africa *Oxford Bulletin of Economics and Statistics*, *65*(3), 283–327. https://doi.org/10.1111/1468-0084.t01-1-00052

Sell, M., and Minot, N. (2018). What factors explain women's empowerment? Decision-making among small-scale farmers in Uganda. Womens Stud. Int. Forum 71, 46–55. doi: 10.1016/j.wsif.2018.09.005

The Republic of Uganda (2013). *Uganda Vision 2040*. Kampla, Uganda. Retrieved from The Republic of Uganda website: http://npa.go.ug/wp-content/themes/npatheme/documents/vision2040.pdf

The Republic of Uganda (2015). *Second national development plan (NDPII) 2015/16-2019/20)*. Kampala, Uganda. Retrieved from https://www.ugandainvest.go.ug/wp-content/uploads/2016/03/National-Development-Plan-2015-16-to-2019-20.pdf

Reynolds, T. W., Waddington, S. R., Anderson, C. L., Chew, A., True, Z., & Cullen, A. (2015). Environmental impacts and constraints associated with the production of major food crops in Sub-Saharan Africa and South Asia. *Food Security*, *7*(4), 795–822. https://doi.org/10.1007/s12571-015-0478-1

Richards, E., Theobald, S., George, A., Kim, J. C., Rudert, C., Jehan, K., & Tolhurst, R. (2013). Going beyond the surface: Gendered intra-household bargaining as a social determinant of child health and nutrition in low and middle income countries. *Social Science & Medicine (1982)*, *95*, 24–33. https://doi.org/10.1016/j.socscimed.2012.06.015

Rogan, M. (2013). Alternative Definitions of Headship and the 'Feminization' of Income Poverty in Post-Apartheid South Africa. *Journal of Development Studies*, *49*(10), 1344–1357. https://doi.org/10.1080/00220388.2013.812199

Seebens, H. (2011). *Intra-household bargaining, gender roles in agriculture and how to promote welfare enhancing changes* (ESA Working Paper No. 11-10). Retrieved from Food and Agriculture Organization of the United Nations website: http://www.fao.org/3/a-am315e.pdf

Smith, L. C., & Chavas, J. P. (2007). Price policy, poverty, and power within rural West African households. *Journal of Development Studies*, *43*(4), 721–742. https://doi.org/10.1080/00220380701260044

Sow, F. D. (2010). *Intrahousehold resource allocation and well-being* (Vol. 10). The Netherlands: Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-714-1

Stahl Ingolf (1972). *Bargaining theory*. Stockholm, Sweden.

UN (2020). *The sustainable development goals report 2020*. Retrieved from United Nations website: https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf

UNDP (2013). *Ecosystem based adaptation in mountain Elgon ecosystem*. Vulnerability Impact Assessment (VIA) for the Mt Elgon Ecosystem. Kampala Uganda. Retrieved from United Nations Development Programme website: https://www.adaptation-undp.org/sites/default/files/downloads/undp_ugandaunepunep-wcmc_2013_uganda_via_report.pdf

Uganda Bureau of Statistics (2016). *The National Population and Housing Census 2014 – Main Report*, Kampala, Uganda. Retrieved from file:///C:/Users/hp/Desktop/03_20182014_National_Census_Main_Report.pdf

Von Eye, A., & Christof, S. (1998). *Regression analysis for social sciences*: Elsevier.

Walter, S. (2018). Non-cooperative decision making in the household: Evidence from Malawi. *Journal of Development Economics*, *134*, 428–442. https://doi.org/10.1016/j.jdeveco.2018.06.008

Weisberg, S. (2002). Dimension reduction regression in R. *Journal of Statistical Software*, *7*, 1-22.

CHAPTER FOUR

SMALLHOLDER FARMERS' MODIFICATIONS AND PRACTICES FOR SITE ADAPTATION AND IMPROVED FARM PRODUCTIVITY[3]

Abstract

Smallholder farmers in the highlands of eastern Uganda experience reduced land productivity and, consequently, face frequent food insecurity episodes. Agroforestry has been identified as a feasible, cost-effective and sustainable approach to improve land productivity, especially in the long run. A range of agroforestry technologies continues to be promoted by government and non-government actors to match the different smallholder farmer contexts. In the study site, boundary planting, intercropping, and woodlot were among the promoted agroforestry technologies. Despite the recommendation by the experts, smallholder farmers continue to modify and develop their own practices (ways) different from what was promoted to make agroforestry useful in their local realities. Some modifications and practices by smallholder farmers have mixed results with both positive and negative outcomes. Adverse outcomes impede others from using similar agroforestry technologies, while positive effects generate incentives for agroforestry technology uptake. However, how the modifications promoted the three agroforestry technologies among the smallholder farmers in the eastern highlands of Uganda eastern highlands is unknown. This study was designed to examine how smallholder farmers' modifications and own designed practices enhanced the use of agroforestry technologies in the eastern highlands of Uganda. This information is vital to promote and scale-up agroforestry technologies. A case study approach was used to answer the following specific objectives (i) establishing the specific contexts under which smallholder farmers modified or generated their practices to improve the usability of the three agroforestry technologies promoted; and (ii) describing the smallholder farmers' modifications and designed practices in adapting the three agroforestry technologies. Regardless of their sex and age, smallholder farmers modified the recommended technologies and designed their own practices to make the promoted agroforestry technologies suit their contexts based on their knowledge, experience, preferences, and priorities. The major modifications and practices were done to enhance tree seedling survival, diversify benefits, optimize space, minimize production

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costs, and shorten the waiting time for tree-related benefits. Although some of their modifications and techniques cast a mirage on the desired outcome of farm productivity, more validation is needed to see how they can be integrated into mainstream agroforestry research and development.

Keywords: **Modifications, practices, case study, usability, farm productivity**

4.1 Introduction

Smallholder farmers play an increasingly important role in the global food value chain (Khalil et al., 2017). Using only 12% of the farmland worldwide, smallholder farmers produce 70-80% share of the world's food Benjamin, 2020; Wolfenson, 2013). For example, smallholder farmers in Sub-Saharan Africa (SSA) provide an estimated 80% of the food produced (Lowder et al., 2016) yet are largely food insecure (IFAD & UNEP, 2013). However, the increasing population, urbanization, and cultural land-sharing practices further reduce small farm sizes. Moreover, increasing pressures from other sources such as land degradation, soil erosion, over-cultivation, and climate change threaten food and income security for millions of people (Gomez et al., 2020). Agroforestry is one of the approaches advocated for and promoted to replenish land productivity and ensure sustainable food security among smallholder farmers.

Agroforestry is an old and traditional practice (Nair, 1993) that has been recently transformed into a science-based discipline (Nair, 2011; Nair, 2007). Whereas agroforestry seems to be defined differently, the common denominator is integrating a woody perennial in a farming system (van Noordwijk et al., 2016). Taking technology as the application of science (Bunge, 1974; Rubba & Harkness, 1993), I adapt the definition of agroforestry technology from Nair (1993). In this context, agroforestry technology is seen as a deliberate science-based intervention where trees are associated with crops under specific functions, location, arrangement, and tree management to improve farm productivity (Nair, 1993), consequently, livelihoods of the rural communities. A range of agroforestry technologies generated through research has been disseminated to smallholder farmers as the primary beneficiaries (Nair, 2007) with expected positive outcomes on the farm if used as recommended. The results include nutrient availability to crops, reduced soil erosion, improved soil fertility, and soil moisture conservation (Karshie et al., 2017), all of which enhance land productivity.

With the emphasis on the experts' recommended practices, agroforestry technologies are primarily promoted through the linear technology transfer model and perceived to be adopted. Yet, adoption is rarely practical in the complex heterogeneous context where smallholder farmers thrive (Giller et al., 2011; Vanlauwe et al., 2016). The impracticability of the linear model producing predetermined outcomes or effects is interpreted differently by different scholars. Whereas some allude to researchers' inability to consider the smallholder farmers' local context and realities (Vanlauwe et al., 2016), others view it as ignorance and uncooperativeness of smallholder farmers (Glover et al., 2017). A recent study conducted by Buyinza et al. (2020) in the eastern highlands of Uganda confirmed that smallholder farmers take up agroforestry technologies mainly due to community norms as opposed to the conventional extension approach. To make technologies valuable and relevant in their local contexts, smallholder farmers often modify the instructed science-based recommendations and, where possible, come up with applicable practices that help solve their challenges. In changing researchers' recommended agroforestry technologies and developing their practices, smallholder farmers disapprove of the researchers' mindset of looking at them as passive recipients. This implies that smallholder farmers, like other actors, play an active role in micro-inventing (van der Veen, 2010) or re-inventing (Rogers, 2010). Due to smallholder farmers' creativity, activeness, and innovativeness using technologies, Leeuwis and Van den Ban (2004) advocate co-designing rather than disseminating technologies.

What a smallholder farmer chooses to take up depends on his/her individual and unique situation that may be contributed to by biophysical, social, economic and psychological realities. In explaining the difference in contexts that influence technology uptake, Rogers (2010) categorises them into relative advantage, compatibility, complexity, trialability and observability (p. 15). The five characteristics are perceived to be the most important in determining the rate at which an innovation or technology is used or re-invented (adopted or adapted). Smallholder farmers do not merely receive and use (adopt) technologies as presented to them for their sake. The nearer a technology is to the smallholder farmer's local contexts and goals, the more it is exposed to adjustments to increase usability based on their experience and goals (Glover et al., 2017).

With the intent to improve farm productivity for enhanced income and food security, smallholder farmers in the eastern highlands of Uganda were introduced to a range of agroforestry technologies through a project referred to as Trees for Food Security (T4FS). The T4FS project was implemented in the eastern highlands of Uganda in 2014 under the partnership of international, national and local actors to expose smallholder farmers to agroforestry technologies and scale up trees within farming systems (Muthuri et al., 2017). The project was implemented through the intensified distribution of tree seedlings, organized training sessions, and on-farm trials. The on-farm trials were intended to collect data on the performance of the preferred tree species on different sites. The on-farm trials also helped spur smallholder farmers' uptake by identifying the appropriate tree species that fit different contexts and their recommended practices, especially spacing, planting pattern, thinning, and pruning. Because trees take longer to establish for the on-farm trials' intentions to be observed and appreciated, existing trees of the desired species on smallholder farmers' fields provided opportunities to demonstrate pruning and thinning and therefore served as on-farm demo plots. Demonstrations complemented the on-farm trials on each of the agroforestry technologies introduced. The agroforestry technologies introduced included boundary planting, intercropping, fodder banks, fruit orchards, and woodlot. From follow-up studies conducted to check progress, only three of the agroforestry technologies were found to be more preferred and most commonly taken up: boundary planting, intercropping, and woodlot (Kabiru et al., 2017; Okia et al., 2016); hence these form the focus of this study. Through demonstrations and on-farm trials, these technologies demonstrated the positive impacts of trees in agricultural landscapes and smallholder farmers were expected to replicate these on their farms.

On-farm trials and demonstration plots promote blueprints (Roo et al., 2019). Smallholder farmers, however, have a history of inventing and re-inventing or adjusting technologies to suit the socio-economic, biophysical and cultural conditions upon which their lives and livelihoods depend (Hockett & Richardson, 2018; Scoones, 2009). Smallholder farmers' concept of creating their own practices and modifying introduced technologies/practices is well-grounded in agricultural enterprises (Kummer et al., 2016; Tambo & Wünscher, 2017, 2018) and other fields. Smallholder farmers' creativity of their practices and modifications increases contextualization, contributing to increased use and diffusion of new technologies (Glover et al., 2017).

In the context of this study, I use two words repeatedly: modifications and practices. Modifications refer to changes or adjustments smallholder farmers made to the agroforestry technology-specific recommendations (tree species, spacing, pruning, and thinning) provided by the experts during the on-farm trials and demonstrations. Smallholder farmers tend to modify the recommended technologies from their own experience and experimentation (Glover et al., 2017). In this case, practice is tagged on what the smallholder farmers developed besides what was recommended by the experts. In reality, smallholder farmers used both to increase agroforestry's usability to enhance land productivity.

Although strict adherence to the recommendations may be desirable to maximise technology's effectiveness in a new setting, smallholder farmers often make changes (knowingly or not) to fit the technologies to their local situations. Researchers and development agents have been relatively quiet about smallholder farmer modifications for many years, often referring to them as mistakes in the implementation process. As such, farmer modifications have remained marginalized and not entered the mainstream research and development agenda. Without modifying, most agroforestry technologies would not fit in smallholder farmers' context and contribute to improving their livelihoods. The reality remains that whereas some modifications and practices may increase uptake and effective use of agroforestry technologies (Cedamon et al., 2018; Fungo et al., 2020), some may produce unpleasant outcomes that would be a disincentive to other potential users of agroforestry (Appiah et al., 2020). The popularity of the three agroforestry technologies (boundary planting, intercropping and woodlot) among the smallholder farmers could allude to smallholder farmers' modifications that made it possible for many to use them. It could also indicate a positive outcome of integrating the smallholder farmers' modifications and practices to utilise agroforestry technologies. Apparently, the smallholder farmer modifications contributing to the uptake and use of agroforestry technologies among smallholder farmers in the eastern highlands of Uganda are unknown. Such information would be helpful to scientists and other agroforestry promoters to enhance agroforestry among smallholder farmers. The strengths of the modifications and practices would be upheld, while the weaknesses would provide improvement opportunities. This study was designed to investigate how the modifications and practices promoted the three popular agroforestry technologies' usability in the different smallholder farmers' contexts. Understanding smallholder farmers' modifications and own designed practices would facilitate developing, introducing, and promoting appropriate agroforestry technologies that meet local realities. With the general research question of how smallholder farmers' modifications and practices enhanced uptake and usability of agroforestry technologies, the study was guided by two specific objectives: (i) establish the specific contexts in which smallholder farmers modified or generated their practices under each of the three agroforestry technologies for improved usability; and (ii) describe the adjustments and practices that were made and the rationale behind each of them. This study contributes to the literature on the adaptation of agroforestry technologies to local contexts. It emphasizes a need for a flexible agroforestry technology development and extension model that encourages smallholder farmers' feedback to reinvent technologies compliant with their context.

4.2 Methodology

4.2.1 Study area

The study was conducted in the eastern highlands of Uganda (also known as the Mt. Elgon region) due to reduced land productivity despite the once fertile volcanic soils (Bauw et al., 2016). Yet, the pressure on land is increasing due to the high population. The eastern highlands also lie in the region with the highest poverty, where 35.7% of the people live below the national poverty line (US$0.88-US$1.04), a figure which is above the national poverty rate of 21.4% (Owori 2020). Efforts of reforestation have been promoted in the eastern highlands, especially along the slopes of Mt. Elgon, to manage erosion and landslides in the highlands (Vedeld et al., 2016). The eastern highland agro-ecological zone is famous for producing the more valued Arabica coffee type, whose yield and quality of cherries are enhanced with appropriate shade trees (Rahn et al., 2018). With the promotion and uptake of agroforestry technologies among smallholder farmers in the eastern highlands of Uganda, it would be exciting to find out how the farmers have modified and designed their own practices to adapt agroforestry technologies into their small agricultural land parcels for improved land productivity. The study was explicitly conducted in the eastern highlands of Uganda in Manafwa and Namisindwa districts in Bugisu. Selection of the two districts was mainly based on (1) long history of over cultivated and less productive soils (Oyana et al., 2015); (2) large chunks of bare sloppy land parcels with high rates of erosion; (3) low tree cover and scarcity of fuelwood; (4) the long engagement of actors like NARO, ICRAF and Mt. Elgon Tree Growers Enterprises (METGE) for over ten years with the districts in promoting agroforestry; and (5) the presence of the Australian funded Trees for Food Security Project (T4FS). The T4FS project promoted agroforestry technologies, and several smallholder farmers in Namisindwa and Manafwa made efforts to take up some of the agroforestry technologies. It would be exciting to get empirical insights from smallholder farmers who participated in the project on what practices and modifications they came up with to utilise agroforestry technologies. One sub-county was purposively selected in each district based on the high concentration of smallholder farmers using agroforestry: Butta and Namabya sub-counties for Manafwa and Namisindwa, respectively.

4.2.2 Research design

A case study approach was the most appropriate to understand how modifications and practices promoted smallholder farmers' uptake and usability of agroforestry in the prevailing situation. Although there are three approaches to case study reflecting on the gurus in this field (Yazan, 2015), the converging point is in conducting an in-depth investigation to understand a complex issue or phenomenon in its real-life context (Creswell, 2009; Crowe et al., 2011; Yin, 2018). In this case, the complex issue that needed to be unearthed included a mixture of modifications, practices (actions), and context (s) that triggered the actions, the rationale behind the farmers' actions and the outcomes or benefits of the actions. That implied a deliberate search to understand the 'what', 'how', 'why' and 'when' questions related to smallholder farmers' changes and practices in making agroforestry technologies suit their local situations. For a richer and more robust investigation, a hybrid of thoughts from Yin (2018), Merriam (1998), and Stake (1995) was used in a complementary way. Understanding the experiences and realities that smallholder farmers go through in enhancing agroforestry technologies' usability required frequent and regular interactions over four months.

4.2.3 Sampling procedure for selection of cases

In this study, 12 cases (selected smallholder farmers that practised specific agroforestry technologies) were purposively selected based on those that exhibited the four parameters: (1) directly participated in all the four agroforestry training sessions organised under the T4FS project; the assumption was that these had more interest and a high chance of integrating agroforestry technologies, (2) those that practised one or more of the three popular agroforestry technologies and had owned land on which the technology was being practised; these had a right and freedom of modifying or coming up with their practices, (3) hosted on-farm trials, and (4) had the desired tree species which they offered to serve as a demo for pruning or thinning. Priority was given to farmers interested, willing, and had time to participate in the study. The presence of the above four parameters in a smallholder farmer was used to indicate that he/she was knowledgeable and experienced enough – aspects necessary in adjusting agroforestry technologies in making them suitable and usable (Hockett & Richardson, 2018; Oyana et al., 2015).

Based on the above criteria, a stratified purposeful sampling procedure (Omona, 2013) was used. The smallholder farmers selected were stratified into the three agroforestry technologies targeted in the study (boundary planting, intercropping and woodlot). When a smallholder farmer practised more than one technology, the stratification was based on the most predominant technology as assessed by the local government extension worker. According to the key informants (local government extension workers), there was no difference in the distribution of agroforestry technologies between the two districts since they both have similar socio-economic and biophysical characteristics. Under each stratum, two sub-strata were formed: age and sex. Although Uganda's constitution defines a youth as one between 18 – 30 years, children in the Gisu community start seeking independence earlier. Hence the age categorization used by the East African Community where a youth is looked at as the person falling in the age category 15-35 (Tayebwa, 2013) was found to apply to this study's context. The age categories created were 15-35 years and 36-64 years, referred to as youths and adults. Under each sub-stratum age category, a female and male smallholder farmer (now referred to as case) was selected, as illustrated in Table 4.1. This led to 12 cases (4 per technology X 3 technologies).

Table 4.1: Selection procedure of the cases for each stratum/technology

Sex of case	**Age of case**	
	15-35 years (youth)	36 – 64 years (Adults)
Male	Male youth	Male adult
Female	Female youth	Female adult

The essence of taking care of age and sex was held on the assumption that the goals, contexts, interests, and expectations of male and female cases of different age ranges triggered various modifications and practices in making the agroforestry technologies useful. The youths, for example, were expected to be more adventurous and creative. Simultaneously, the adults could have a richer experience leading to unique modifications and practices while utilising the technologies. Likewise, the male and female cases were perceived to have different interests in agroforestry. Whereas females could look at trees (agroforestry) searching for domestic needs such as food and firewood, the males could be interested in income generation. If the case had more than one technology, s/he was also engaged in other technologies to complement information from other cases. Due to the mountainous nature of the eastern highlands, the selection of cases in each stratum where possible was done while taking into consideration where possible the three slope categories classified by altitude as up-slope (>1,625 m asl), mid-slope (1,164-1,625 m asl) and down-slope (398-1,164 m asl) (UNDP, 2013). A given slope category could influence how a particular case modifies or generates practices to suit an agroforestry technology to their context.

4.2.4 Data collection

Data was collected over four months of frequent and regular interaction with the cases using various formal and informal methods, including in-depth interviews, conversations, discussions, and direct observations of the field's practices and modifications. These methods complement each other and enhance the robustness of data and validity of the study. Different evidence sources are one of the major strengths of a case study (Crowe et al., 2011; Yin, 2018). Informal conversations are a great way of relaxing the respondent and enhancing rapport (Fritzen-Pedicini et al., 2019; Swain & Spire, 2020). Open-ended questions guided the individual in-depth interviews while an observation checklist guided what to look for in the field (the practice, the change made, how the change was made, and the crops' performance adjacent to the tree). Interviews were conducted in local languages, mostly Lugisu but often mixed with Luganda to ensure that both sides (interviewer and respondent) understood each other. The researcher knew Luganda but hardly spoke Lugisu.

On the other hand, the cases spoke Lugisu but could understand Luganda. The two languages are related and share many words in common: Bantu. An audio recorder was used to keep the conversation uninterrupted in capturing all the conversation details. Before using the recorder, each case was briefed on the reason, and permission was sought for comfort in its use. Field notes were made too during each interaction interview/discussion with a trained research assistant (note taker). Direct observations were made to see and confirm the modifications and practices, understand their actual uses, and ascertain the adjacent crops' condition, suggesting their implications on-farm productivity.

4.2.5 Data analysis

Data from the cases were reviewed, and aligned to the same thing was pulled together as emphasized by Yin (2018). Audio-recorded data were transcribed verbatim (from voice to text) with a research assistant who understood the three languages: English, Lugisu, and Luganda. The responses were in Lugisu and sometimes in Luganda, but the text had to be directly translated and transcribed in English. No interpretation was made yet at the transcription level; the focus was on data collected first. Field notes and transcribed data collected from conversations and discussions were aligned before reducing the data. Data reduction is vital in sorting and organising the data for easier generation of conclusions (Namey et al., 2008). Structural coding (question-based), which was done by linking the data to the research questions, enhanced the reduction process. Emerging themes and patterns were identified from the comprehensively reduced data. As explained by (Ryan & Bernard, 2000), the keywords (e.g., context, modification, practice) guided the generation of themes and patterns. Respondents' direct quotes were used to emphasise the reasons for the modifications.

4.3 Results and Discussions

4.3.1 Description of the cases

Before delving into the practices and modifications used in enhancing the use of agroforestry technologies, I must describe each of the cases (Table 4.2) and their contexts. This would provide a clue or better understanding of how their contexts might have accounted for their modifications or own practices. As narrated by Yin (2018), Stake (1995), and Merriam (1998), context plays a critical role in understanding the activities and functioning of a case. The descriptions, however, were aligned and focused on the direction of the study. The cases' names are anonymous, but the characteristics or situations were accurately described. The number assigned to a case is just for identity; it had nothing to do with prioritising their importance.

(a) Cases under boundary planting

Case 1: The case was a male youth (28 years) whose farm was located down-slope in Butta sub-county Manafwa district. He lived with his wife and their two children. Farmer attended formal education up to primary seven. His land was 1.2 acres and was dominated by annual crops such as beans (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta*), and sweet potatoes (*Ipomoea batatas*). He also kept local chickens and goats. He started working with the Trees for Food Security project in 2015. Apart from farming, the case had no off-farm income-generating activity. He lived in an area that was prone to strong winds. He took up the boundary technology in 2016 to control soil erosion and break the wind. The agroforestry plot is located near the homestead.

Case 2: The participant was an adult male (42 years old) who lived with his wife and seven children, and his farm was located in the mid-slope in Butta sub-county, Manafwa district. He was educated up to primary six. His farm was 2 acres. He mainly cultivated beans, maize, and sweet potatoes and had some banana (*Musa* spp.) and Arabic coffee (*Coffea arabica* L.). He started working with the T4FS project in 2014. Farming is the primary source of livelihood for the family. The agroforestry plot, located near the homestead, was established in 2015.

Case 3: A female youth (33 years old) located in the up-slope in Namabya sub-county Namisindwa district. She was married to a civil servant working at Mbale district. They had four children but also five other dependents who stayed with them. She was a nursery teacher but not involved in teaching at the time. The husband usually came back on weekends and was not actively engaged in farming. They had 3 acres of land where they grew both annual crops (beans, cassava) and perennial crops (bananas). She started working with the T4FS project in 2015 because she was interested in planting trees to shield her crops against the strong winds. She was specifically interested in eucalyptus because it grows very fast.

Case 4: This was a female adult (44 years old) whose farm was located mid-slope. The participant was a single parent heading a family of six members in Butta, Manafwa district. She was educated up to primary four. She had 2 acres of land. She mainly relied on family labour but sometimes supplemented it with hired labour during weeding. She mainly cultivated annual crops such as beans, maize, cassava, coffee, and banana. She also kept cattle (two cows) that provided milk for sale and dung for fertilizers. She had been a contact smallholder farmer for the T4FS project since 2015.

(b) Cases under intercropping

Case 5: A youthful female smallholder farmer (35 years old) whose farm was located in the mid-slope in Butta sub-county, Manafwa district. She had five members in the household. The husband was a boda-boda rider in Manafwa, also involved in part-time trading in agricultural produce. Since the husband was busy with off-farm activities, she mainly fed the family. Their land was 1.5 acres and primarily used to grow annual crops like beans, cassava, maize, and sweet potato, although they had bananas. She also planted climbing yams for food and income security. The agroforestry plot near the homestead and trees was integrated in 2016 when she worked with the T4FS project.

Case 6: An adult female smallholder farmer (49 years old) located in the up-slope in Namabya sub-county, Namisindwa district. She had been separated from her husband since 2013 and now heads a family of 6 members. The first daughter got married in Mbale while the eldest son was employed in a telecom company in Iganga. These children were remitting some money that helped in running the household. She cultivated land of 2.5 acres where she grew coffee and banana and annual crops like beans, maize, and cassava. She was passionate about planting trees on her farm. She cultivated mangoes and passion fruits, mainly for income generation. During the season, the market was readily available, and she used to get reasonable sales to solve some of the household problems.

Case 7: A male adult smallholder farmer (53 years old) located in the mid-slope in Butta sub-county Manafwa district. He held a certificate from Nyabyeya Forestry College. He had worked with the Vi Agroforestry project in Masaka but decided to return home after the father's death to concentrate on farming. His land was 4 acres, but he could also utilize some of the land that belonged to his siblings, who were not around if he needed more land. He was very knowledgeable about trees and the knowledge and experience he accumulated while still working for an agroforestry project in Masaka. Because of his experience, he was a contract farmer for most of the area's projects, including the T4FS project. He mainly cultivated perennial crops like coffee and banana for income and seasonal crops like beans and maize for home consumption. He also kept cattle, goats, sheep, and local chicken. He volunteered to teach other farmers about the different aspects of agroforestry.

Case 8: This was a female youth (29 years old) located in the down-slope in Butta, Manafwa district. She was educated up to senior three. The family had six members. The husband worked at the district and was rarely involved in farming. Most of the children were still young, attending school from home. They had 1.5 acres of land to grow bananas, coffee and beans. She was a member of a village saving group, and it was from here her friend asked her to participate in the T4FS project where she got tree seedlings to plant on her farm. The trees in the agroforestry plot were established in 2016. The agroforestry plot is located near the homestead. When she joined the T4FS project in 2016, the trainers brought seedlings and established a trial on her farm, but most seedlings did not perform well because of the drought. Although they have a small plot of land, she kept adding trees for shade and firewood.

(c) Cases under a woodlot

Case 9: This was an adult female smallholder farmer (aged 49 years) located in the down-slope in Namabya, Namisindwa district. She operated a 2 acres piece of land. Five people lived in the household, but the number often increased to 9 during holidays. She was in charge of farming because her husband was a teacher based in Mbale town. The agroforestry plot (woodlot) was located towards the swamp, a bit away from the homestead where the land was previously unproductive. Hence, she planted eucalyptus in 2015 to make the plot productive. She mentioned that the planting of eucalyptus ensured a regular flow of income in the house because there was always someone who wanted to buy firewood or poles. She mainly cultivated tomatoes, cabbage, eggplants, beans, maize, and banana.

Case 10: This was a male youth (aged 35 years) located downslope in Namabya sub-county, Namisindwa district. He had three pieces of land, all summing up to 2.5 acres. He was educated up to senior three and married with five children. He was passionate about tree planting on his farm. He cultivated coffee, bananas, beans, maize, and yams. He also kept livestock such as goats and cattle. He established a eucalyptus woodlot adjacent to the stream in a plot that experienced seasonal waterlogging. Before establishing the woodlot, flooding had made crop production in the plot very difficult. He could now harvest poles and firewood that he sold to community members. He was a contact farmer (tree seedling distributor) for the T4FS project in Namabya.

Case 11: This was an adult male smallholder farmer (aged 48 years) in the mid-slope in Butta sub-county, Manafwa district. There were seven members in the household that mainly depended on agriculture for their livelihood. The land size was 3.5 acres. They mainly cultivated bananas, beans, maize, Irish potatoes, millet, and yams. They also kept pigs and local chickens. The woodlot was established on the lower side of the farm, which experienced occasional waterlogging. The eucalyptus woodlot he established in 2016 with free seedlings from the T4FS project helped drain the plot's water. The woodlot now supplied the family with poles for domestic construction and firewood.

Case 12: This was a female youth participant (aged 34 years) located in the mid-stream in Namabya sub-county, Namisindwa district. The husband was a policeman based in Sironko. Although the husband remits some money, she is directly responsible for taking care of the family of 8 members. The land owned by the family is 1.5 acres, where they mainly cultivated tomatoes, Sukuma wiki, and cabbages for sale using family labour. Also, she grew beans, maize, and matooke mainly for home consumption. The woodlot, established in 2016, was mainly for timber production, but she could get stakes for tomatoes and beans after pruning.

4.3.2 Description of the agroforestry technologies as recommended

As already stated in Chapter 1, agroforestry technologies were promoted among smallholder farmers with underlying guidelines that stipulated the tree species, their planting patterns, spacing, and management options (pruning and thinning). The technologies were supposed to be replicated by the smallholder farmers to enhance farm productivity. Below is a description of the agroforestry technologies popularised during training and demonstration sessions.

The boundary planting agroforestry technology

The trees under the boundary agroforestry technology were intended to delimitate agricultural fields while providing products and services for subsistence and income generation. The boundary agroforestry technology was promoted among smallholder farmers with underlying recommendations regarding appropriate tree species, planting patterns, spacing, and pruning. The technology was supposed to be replicated by the smallholder farmers to enhance farm productivity. In the boundary planting agroforestry technology, smallholder farmers had to systematically plant trees on the edge of the plot where crops were being grown. In addition, the trees were supposed to be planted in a single tree line.

The experts' recommended tree species included *Maesopsis eminii* Engl., *Cordia Africana* Lam, *Albizia coriaria* Welw., *Grevillea robusta* A.Cunn. ex R.Br. at a spacing of 10 m within the line. Other recommended species were *Melia volkensii* Gürke and *Neolamarkhia cadamba* Roxb at 6 m and 8 m, respectively, within the line. *Calliandra calothyrsus* Meisn. was also recommended at a spacing of 60 cm in the line and a cutting height of 50 cm for fodder. At the recommended spacing, there was no need for thinning. However, both root and canopy pruning were recommended after two years. After that, root pruning would be done every season as smallholder farmers weeded their crops to minimize below-ground competition for nutrients with adjacent crops. Proper root pruning was supposed to be undertaken by digging a trench of about 1.5 ft, 50 cm from the tree on either side of the boundary line. This would disconnect the roots that were likely to compete with those of the adjacent crops in the upper soil zone, thereby encouraging the tree to feed from the soil's deeper layers. In addition, after two years, canopy pruning involving removing side branches was recommended to minimise the tree branches' shading effect on the adjacent crops. During the canopy pruning, all the side branches that shade the adjacent crops were supposed to be smoothly cut using an arc saw 30 cm from the trunk. A smooth cut was vital to quicken the tree wound's healing process and avoid infestation of pests and diseases.

The intercropping agroforestry technology

This technology involved the systematic integration of trees in the cropping fields. In the intercropping agroforestry technology, the recommended tree species were supposed to be planted in lines (alleys) at a specified spacing. For easy management of tree-crop interactions, given that tree species possess different growth behaviour, it was appropriate that the smallholder farmer chose only one tree species from among the alternatives. The recommended tree species included *Maesopsis eminii*, *Cordia africana*, *Albizia coriaria* at a 10 x 10 m spacing, and *Melia volkensii* at 8 x 8 m spacing. Under the recommended spacing, thinning was not required. However, trees were supposed to be pruned (both root and canopy) to control tree-crop competition for light, growing space, soil water, and nutrients. Hence, root pruning was recommended as early as two years by digging a trench (in the form of a ring around the tree) 1.5 ft deep, 50 cm from the tree. The established trench would ensure that all the tree's shallow roots that were likely to compete with adjacent crops for soil water and nutrients would be cut. The smallholder farmer was encouraged to maintain that trench every season using a hoe. After two years, canopy pruning was recommended to remove the side branches shading the adjacent crops. Pruning was to be done with a smooth cut using an arc saw 30 cm from the tree trunk. The smallholder farmer was supposed to be looking for such branches to prune them early enough before over-shading the adjacent crops.

The woodlot agroforestry technology

The woodlot agroforestry technology was promoted in response to the growing demand for tree-based products such as poles for construction, timber and firewood. Trees were supposed to be planted in a pure stand at regular spacing. The recommended tree species included *Eucalyptus grandis* and *Grevillea robusta* at a spacing of 3 x 3 m. Other tree species included *Melia volkensii,* and *Neolamarckia cadamba* spaced 4 x 4 m and 5 x 5 m, respectively. Canopy pruning was not required for *Eucalyptus grandis* since its self-pruning. However, for the other recommended tree species, and in line with the timber objective, canopy pruning was recommended after two years to produce note-free timber. Pruning was supposed to be done using an arc saw to ensure a smooth cut for the wounds' quick healing. For timber-oriented woodlots, thinning was recommended as early as two years for *Eucalyptus grandis* and 3-4 years for the other tree species. Thinning was aimed at the removal of deformed or stunted trees.

4.3.3 Smallholder farmers' modifications and practices

Smallholder farmers' modifications have been summarized in Table 4.2 together with their positive and negative management findings. The smallholder farmers' modifications and their own practices are discussed according to the predominant agroforestry technologies promoted in the eastern highlands of Uganda. Elgon region. Each agroforestry technology was subjected to some form of adjustment across all cases. The adjustments or changes were observed in tree species, planting patterns, spacing, thinning, and pruning. Besides the smallholder farmers' modifications, their own practices to enhance the usefulness of trees and consequently agroforestry technologies were also reported by the cases. Regardless of the sex and age, all cases modified the recommended practices while utilising a given agroforestry technology. All cases modified spacing during the utilisation of the agroforestry technologies. Eight out of the twelve cases reduced the recommended spacing when planting the tree seedlings while the rest (four) randomly planted the trees. Six of the cases (four females and two males) were not thinning or pruning their trees despite the importance of these management operations in reducing competition and ensuring high quality and timber quantity. Besides the modifications, own-generated practices enhance the trees' useability, and consequently, agroforestry technologies were also reported by 9 cases (Table 4.2). These own practices included ring-fencing, companion planting, planting tree seedlings adjacent to banana stools, spot-mulching, injuring fruit trees, relay planting, and integrating annual crops in woodlots.

The boundary planting cases modified the planting pattern (sometimes preferring a double line boundary to the recommended single line). The spacing (reducing it from the recommended) and thinning or pruning were not undertaken. Cases 2 and 3 used *Markhamia lutea* and *Eucalyptus grandis,* respectively, two species that were not on the recommended tree species under boundary planting.

Under the intercropping agroforestry technology, all the cases modified the tree species, preferring to use a combination of tree species rather than single species, some of which were not on the recommended list (*Neolamarkhia cadamba*, *Mangifera indica*, and *Persea americana*). Also, cases used closer spacing than was recommended for the individual tree species. Pruning or thinning was not done for 2 out of 4 cases selected under the intercropping technology. However, farmers were found to adhere to the recommended crop combinations.

In the woodlot technology, all the cases modified the spacing. Pruning or thinning were also rarely done by the smallholder farmers as recommended by the experts. Three cases utilising the woodlot technology (Cases 9, 10, 11) used the recommended tree species in a pure stand arrangement apart from case 12, which used a mixture of different tree species (*Neolamarkhia cadamba* and *Grevillea robusta*). For cases that pruned their trees, canopy pruning was done to reduce above-ground competition. The absence of cases that undertook root-pruning in the boundary planting and intercropping technologies highly recommended implies that belowground competition for soil nutrients and water was not regulated. Canopy pruning using a panga instead of a bow or arc saw recommended to leave a smooth cut was common.

Table 4.2: Summary of the context under which agroforestry technologies were modified

Case	Agroforestry Technology	Farm location	Age	Sex	Marital status	Family size	Education (years)	Land size (acres)	Main agricultural enterprises	Farm challenges
1	Boundary	Downstream	28	M	Married	4	7	1.2	*Crops*: maize, cassava, beans *Livestock*: goats and chicken	Strong winds Soil erosion
2	Boundary	Midstream	42	M	Married	9	6	2.0	*Crops*: beans, maize, sweet potatoes, bananas and coffee	Soil erosion
3	Boundary	Upstream	33	F	Married	11	15	3.0	*Crops*: beans, cassava and bananas	Strong winds
4	Boundary	Midstream	44	F	Separated	6	11	2.0	*Crops*: beans, maize, cassava, coffee and banana *Livestock*: 2 dairy cows	Soil erosion
5	Intercropping	Midstream	35	F	Married	5	7	1.5	Crops: beans, cassava, maize, sweet potato, bananas, climbing yams	Soil erosion
6	Intercropping	Upstream	49	F	Separated	6	5	2.5	*Crops*: beans, maize, cassava, coffee and banana	Soil erosion
7	Intercropping	Midslope	53	M	Married	5	16	4	*Crops*: beans, maize, coffee and bananas *Livestock*: cattle, goats, sheep and chicken	Soil erosion
8	Intercropping	Downstream	29	F	Married	6	10	1.5	*Crops*: beans, banana and coffee	Drought
9	Woodlot	Downslope	49	F	Married	9	7	2.0	*Crops*: tomatoes, cabbage, eggplant, beans, maize and banana	Flooding
10	Woodlot	downslope	35	M	Married	7	10	2.5	*Crops*: beans, maize, yams, coffee and banana *Livestock*: cattle and goats	Flooding
11	Woodlot	Midstream	48	M	Married	7	7	3.5	*Crops*: bananas, beans, maize, Irish potatoes, millet, yams *Livestock*: pigs and local chicken	waterlogging
12	Woodlot	Midstream	34	F	Married	8	7	1.5	*Crops*: beans, maize and banana	Soil erosion

4.3.4 Categorizing smallholder farmers modifications and practices

In this study, I looked at smallholder farmers' modifications as practical techniques to help them adapt agroforestry technologies to their farms. These modifications were context-based and were made by the smallholder farmer on their initiative to overcome existing farm and livelihood challenges without any external influence. From the cases, several modifications were made by the smallholder farmers in addition to their own practices across the three agroforestry technologies (Table 4.3). The highest number of modifications (5) was recorded under the boundary planting technology, followed by the woodlot (2) and intercropping technology (1) (Table 4.3). For smallholder farmers' own practices, the highest number was recorded in the intercropping technology (5), followed by woodlot (3). The high number of modifications under the boundary planting technology could be attributed to the fact that planting trees on field boundaries has evolved with the farmers since time immemorial. As such, farmers had a lot of experience, which they based on to modify the technology. All twelve cases shared how their modifications and practices benefited them in various ways to make agroforestry technologies more useful in their contexts. Five broad categories of modifications and practices based on their advantages were generated from the data collected: i) seedling survival enhancing, ii) benefit diversifying, iii) space optimising, iv) production cost-minimizing, and v) (Figure 4.1).

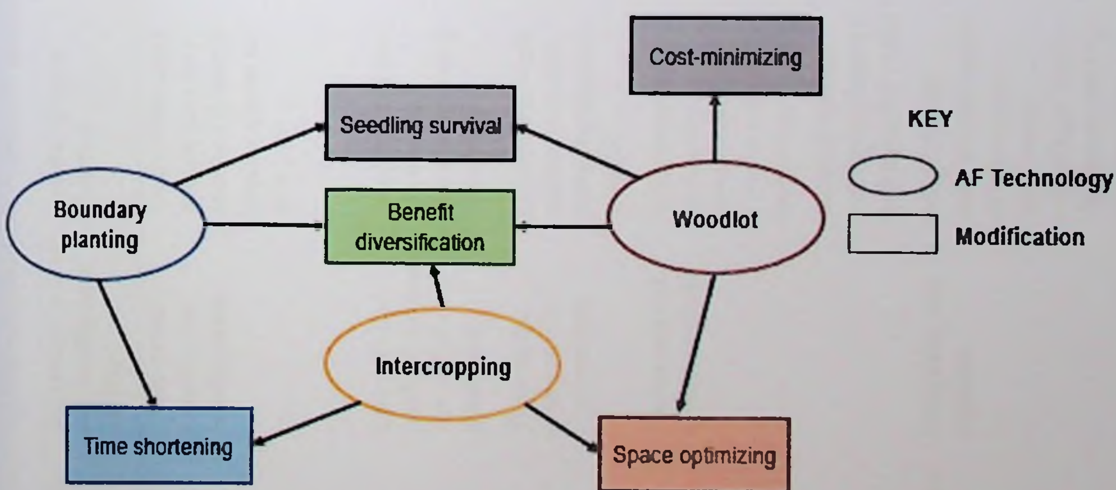

Figure 4.1: Smallholder farmer modifications and own practices

Table 4.3. Summary of the smallholder farmers' modifications and own practices

Case	Agroforestry Technology	Main objective of the smallholder farmer	Modification or Practice	Positive management findings	Negative management findings	Remarks
1	Boundary	Trees on the boundary as windbreakers	Double-line multi-species boundary: involved three tree species spaced at 1 m x 1 m	More effective boundary as a windbreak Diversified tree products from different species	Trees had small boles due to competition	Tree species integrated should have complementary traits to avoid negative competition
2	Boundary	Diversify tree products for home use and income generation	Integration of fruit trees in the boundary planting technology	Diversified tree products	Conflicts with the neighbour	Proper maintenance of trees on the boundary by pruning the branches that extend to the neighbour's plot
3	Boundary	Trees on the boundary as windbreakers	Double-line single species boundary using *Eucalyptus grandis*	Eucalyptus is fast-growing and firm against wind-throws	Poor performance of adjacent crops was observed	Farmers should be discouraged from using *Eucalyptus* grandis on the boundary near crops
4	Boundary	Fodder and soil erosion control	Integration of *Calliandra calothyrsus* in the boundary planting technology	Enhanced soil erosion control and fodder availability		Integration of calliandra with other tree species could help to make the boundary planting technology more useful to smallholder farmers with livestock
			Reduced spacing and cutting height of calliandra for fodder	Increased fodder production for livestock		With reduced spacing, it serves as a hedge that can prevent soil erosion in step areas
5	Intercropping	Diversified tree products	Integration of multiple tree species in intercropping agroforestry technology: used *Maesopsis eminii*, *Neolamarckia cadamba* and *Albizia coriaria*,	Products such as firewood and services were likely to be obtained	Overshading of crops	Management of tree shade was needed to enhance production

			Using trees to support climbing yams*	Enhanced food and income security		This practice should be promoted for food security among smallholder farms
6	Intercropping	Firewood, food and improved yield of coffee	Integration of multiple tree species in intercropping agroforestry technology: used *Maesopsis eminii* and *Albizia coriaria*	Tree products such as firewood and timber and services like shade and soil fertility were being attained	Overshading of crops	More on-farm interventions were needed on how to mitigate the overshading of crops through appropriate pruning and removal of some trees
			Planting the tree seedlings adjacent to banana stools*	Enhanced survival of tree seedlings	Reduced vigour of banana plants over time as trees establish	Adequate spacing to minimize direct competition for water and nutrients
			Spot-mulching of the tree seedlings using banana pseudo-stems*	Enhanced survival and establishment of tree seedlings	Dump environment around the seedlings could potentially attract pests and diseases	Some space should be observed from the root collar to protect the trunk from constant soil moisture
7	Intercropping	Firewood, food and income security	Integration of multiple tree species in intercropping agroforestry technology: used *Neolamarckia cadamba*, *Persea americana* and *Mangifera indica*	Diversified products (fruits, staking fruits), shade for coffee	Dense shading on adjacent coffee and banana plants	Training on tree management to minimize overshading
			Injuring of fruit trees to induce early and high yielding*	Early and quick yielding reported by the smallholder farmer	Tree injuries could be entry points for pests and diseases	
8	Intercropping	Soil fertility and shade for coffee	Integration of multiple tree species: used *Albizia coriaria* and *Cordia Africana*, *Melia volkensii* and *Maesopsis eminii*	Diversified products (e.g., firewood, timber) and services (e.g. shade, soil fertility)	Overshading of crops	Tree shade management needed

			Planting the tree seedlings adjacent to banana stools*	Enhanced survival of tree seedlings	Reduced vigour of banana plants over time as trees establish	Adequate spacing to minimize direct competition for water and nutrients
9	Woodlot	Draining the water in the occasionally flooded plot	Close spacing to reduce stump sizes in the woodlot: used Eucalyptus grandis at 1m x 1 m.	Weed suppression Increased stocking density	The modification is not appropriate for woodlots managed for timber	This modification can be promoted for firewood managed woodlots
			No thinning in the woodlot*	Trees could be selectively harvested based on customer's preferred sizes	The tendency for trees to grow thin	This could be appropriate for firewood and poles but not timber
10	Woodlot	Income generation	Relayed planting of eucalyptus trees in the woodlot*	Continued harvesting of firewood and poles	Etiolation and stuntedness of some trees due to overcrowding	There is a need to understand the appropriate stocking density to avoid overcrowding
11	Woodlot	Food and income security	Integrating cocoa yams in the woodlot*	increased food and income security Improved weeding of the woodlot		For woodlots established in areas of seasonal floods, cocoa yams could be integrated for food and income security
12	Woodlot	Diversity of tree products	Multiple tree species woodlot: used *Eucalyptus grandis*, *Melia volkensii* and *Neolamarckia cadamba*.	Potential to generate several products, e.g. firewood, staking sticks, timber	Management of the woodlot became more complex	Knowledge of complementary traits of tree species is needed to improve the performance of the mixed tree species woodlot

*Practices designed by smallholder farmers to increase the relevance of agroforestry technologies to their context

Seedling survival enhancing practices

Smallholder farmers devised their own practices to enhance survival and the establishment of tree seedlings. Such practices were mainly observed in the intercropping agroforestry technology. This could have been so due to the value attached to the tree species under this technology. Some of the tree species that smallholder farmers incorporated (such as *Maesopsis eminii*, *Persea americana*, and *Albizia coriaria*) were scarce and expensive to get. Among the 4 cases under intercrop technology, two (Cases 6 and 8) were involved in seedling survival enhancing practices. Their own practices were mainly geared towards providing moisture to the seedling throughout the year, especially during the dry spells. In Namabya and Butta, high temperatures (especially during January, February, March, June and July) threaten the survival of seedlings at the early stages of establishment. To minimize the adverse effects of drought on the tree seedlings, spot mulching and planting adjacent to banana stools were used. In both practices, banana plants played a role. Each practice is described in detail below.

(a) Planting tree seedlings adjacent to banana stool

The experience of seedlings being distributed late made some cases (case 6 and 8) to plant the seedlings adjacent to banana stools. Case 6 came up with her practice out of her own experience as narrated, "*From my experience, the avocado tree seedling that I once accidentally planted adjacent to an established banana stool grew very well and vigorously with dark green good-looking leaves. This made me do the same to my Albizia coriaria and* Avocado *seedlings*". Besides tapping from the moist soils, the broad long banana leaves provided shade that protected the seedling and the soil from direct scorching sun rays. The seedling 'enjoyed' a conducive cool micro-climate provided by the banana plants. Whereas the practice improved survival and the establishment of tree seedlings in the short run, the interaction was likely to result in unforeseen and probably undesirable adverse outcomes. In the long run, as the seedling establishes into a tree, it outcompetes the banana plant underneath. The banana plantation increasingly reduces vigour and productivity; some communities simply refer to it as 'bananas disappearing.' This outcome could discourage the future uptake of such agroforestry technologies. Therefore, adequate spacing is important regardless of a tree species' suitability in a banana plantation. Integrating trees in any crop requires that both components have ample space to minimize direct competition for water, light, and soil nutrients (Livesley et al., 2000; Muhammed, 2019).

(b) Spot-mulching of the tree seedling

Case 6 also planted *Maesopsis eminii* in coffee and banana. She cross-cut banana pseudo-stems into pieces of about 1ft, which were split using a panga and laid around the *Maesopsis eminii* seedlings with their succulent sheaths facing downwards (Figure 4.2). She had always used the same practice while planting coffee seedlings. The cut pseudo stem's succulent sheaths take longer decomposing with this practice while ameliorating the temperature and moisture around the seedlings' root zone. Weeds, too, are suppressed around the seedling, minimizing tillage that would damage the fragile roots. Although it takes time, this practice is very affordable, given the readily available pseudo-stems in the study area's farming system. However, a dump environment could be a potential harbour and source of pests and diseases (like moulds/fungi) that may affect the seedlings (Alves & Nunes, 2017; Zhang, Koc, Wang, & Jiang, 2018).

Figure 4.2: Spot mulching of *Maesopsis eminii* seedling using banana pseudo-stems

Benefit diversifying modifications and practices

Smallholder farmers modified agroforestry technologies to meet their diverse household needs. For example, 8 out of 12 cases (Cases 1, 2, 4, 5, 6, 7, 8, and 12), instead of using a single tree species as recommended, used multiple tree species to take advantage of the different benefits offered by trees species (Table 4.1). The use of numerous tree species simultaneously occurred while utilising all three agroforestry technologies.

(a) Use of double-line multi-species boundary

In boundary planting, Case 1, who lived in an area prone to strong winds, incorporated three tree species in a double line boundary spaced at 1 m x 1 m. This, according to the case, created multiple-layered canopies that were more effective as windbreakers than a single layer. Although the double-line boundary planting priority established an effective windbreak structure, the case also anticipated harvesting several tree products, including firewood and timber, from the different tree species (*Neolamarkhia cadamba, Melia volkensii, Grevillea robusta, Eucalyptus grandis*) in the long run. Literature shows that trees planted along boundaries can be significant sources of tree products, including timber, income, and domestic purposes (Doddabasawa et al., 2020). However, due to competition for growing space and soil nutrients, the trees might not grow big in a closely spaced double line arrangement pattern, and they will grow taller and thinner with limited branching. Thus, the trees' limited space for growing reduces firewood and timber quantity likely to be harvested by the smallholder farmer(Rais et al., 2020).

Figure 4.3: Double line multi-species boundary

(b) Use of double line single species boundary

Case 3, located in an area prone to strong winds, chose to use a double line boundary of *Eucalyptus grandis.* Although *the experts did not recommend eucalyptus grandis* for boundary planting, its attributes appealed to the case. From the case's experience, *Eucalyptus grandis* is fast-growing and firm against wind-throws, making it ideal for her farm's context. However, field observations showed that the adjacent banana crops performed poorly despite good management (weeding, pruning). This could probably be attributed to Eucalyptus's allelopathic nature that reduces adjacent crops' productivity (Qin et al., 2018). This further strengthens the experts' argument that eucalyptus is inappropriate along the boundary where crops grow adjacent.

(c) Integration of fruit trees in the boundary planting technology

Case 2 integrated fruit trees (*Mangifera indica* L.) with other tree species (*Neolamarkhia cadamba* and *Markhamia lutea*) along the boundary to tap into the different tree products such as fruits firewood, and timber. *Neolamarkhia cadamba* was the only recommended tree species he used. According to the case, *Markhamia lutea*, an indigenous tree species, is highly adaptable to the boundary conditions, fast-growing with sprouting ability. It's traditionally used for boundary marking, herbal medicine, poles and timber. In addition, the fruit trees provided mangoes for home consumption and income generation. The case, however, reported that he had conflicts with the neighbour when the trees he planted at the boundary extended their branches to the neighbour's plot. This prompted him to prune the branches facing the neighbour's side intensively. Conflicts with neighbours emerge when large trees with widespread roots and canopies are planted along the boundary (Muhammed, 2019). In this case, *Neolamarkhia cadamba* and *Mangifera indica* exhibited large dense canopies and needed to be pruned. To avoid intense pruning, trees with narrow canopies should be considered more appropriate, more still when planted at a distance that does not let the leaves/canopy extend to neighbour's fields.

(d) Integration of *Calliandra calothyrsus* in the boundary planting technology

Case 4 integrated *Calliandra calothyrsus*, a short-term shrub, into the single line boundary of *Melia volkensii*. In this context, the case used *Melia volkensii* to demarcate her plot from the neighbour's. However, she later learned of calliandra as a good fodder shrub that could support her livestock enterprise. The case integrated *Calliandra calothyrsus* in the boundary at a spacing of 2 ft for fodder and soil erosion control. Thus, she harvested fodder for livestock, while the close spacing helped control soil erosion. Whenever there was a lot of calliandra biomass during the rainy season, the case harvested the biomass and placed it between crop rows as mulch, thus providing erosion and weed control before decomposition. Literature shows that in cases where biomass is used as a green mulch, its decay enhances soil nutrients and organic matter in the garden (Muir, 2019). Besides direct nitrogen fixation, calliandra leaves decompose fast to add nutrients to the soil, making them ideal for green manure (Mucheru-Muna et al., 2014).

(e) Integration of multiple tree species in intercropping agroforestry technology

Cases preferred to use a combination of tree species rather than a single species as recommended to diversify tree benefits. For instance, cases 6 and 7 incorporated fruit trees such as avocado (*Persea americana*) and mango (*Mangifera indica*), which were not recommended in the intercropping technology, with *Maesopsis eminii* and *Albizia coriaria* at random spacing. Taking case 6, for example, *Maesopsis eminii* was intended for firewood and temporary shading, while mangoes and avocados provided fruits for household food and income security. She had initially planted *Maesopsis eminii* for firewood and quick shading of coffee. However, she planned to remove all the *Maesopsis eminii* trees for firewood by five years because they were fast-growing and leave *Albizia coriaria*. She considered *Albizia coriaria* a more suitable tree species for shading coffee and banana. Case 7 integrated *Neolamarkhia cadamba* for firewood with fruit trees to enhance food and income security.

The firewood and fruits could be used domestically while the surplus sold off for income. Under the intercropping technology, case 8 combined several tree species in coffee to improve soil fertility, provide shade for better quality cherries (*Albizia coriaria* and *Cordia africana)*, and produce timber (*Melia volkensii* and *Maesopsis eminii*). This modification of using both recommended and unrecommended tree species helped the case to get several products such as firewood and fruits while shading the coffee and protecting the soil at the same time. This string of benefits made intercropping technology more usable for those who had to support a big family. Although case 7 was harvesting fruits from the mangoes and avocados, there were observable effects of their dense shading on the adjacent coffee and banana plants which were acknowledged by the case: "*The coffee trees adjacent to the mango trees do not perform well, possibly due to limited light*". This comment seems to provide evidence that smallholder farmers are observant of the changes in the performance of their crops when they integrate trees on their farms. The opportunity cost of retaining these trees on the farm should make environmental and socio-economic sense to the smallholder farmers for the trees to be retained. In line with the observation of case 7, some studies have pointed out that fruit trees like Mangoes are inappropriate in cropping systems due to their dense shading effect (Qiao et al. 2019). Because the space is highly limiting for smallholder farmers, managing trees and crops for positive interactions is critical (Tafere and Nigussie 2018). For example, *Maesopsis eminii* has deep taproots and a complex network of lateral roots penetrating the soil, allowing the tree to utilise resources from shallow and deep soil layers, thus supporting its fast-growing and competitive habits (Epila et al. 2017; Mulyono et al. 2020). Therefore, even under five years, *Maesopsis eminii* is likely to compete for nutrients with crops and, consequently, reduce crop productivity unless root-pruning is appropriately done. However, all the cases were not practising root pruning because it's laborious.

(f) ***No thinning in the woodlot***

Case 9 had initially established the woodlot for firewood. However, she noticed that she could earn income from selling poles as explained: "*I harvest trees in my woodlot mainly to sell poles. Poles give me more regular income than I could get from the sale of firewood" It is the offshoots that I then sell or use for fuelwood.* " For this case, it was not necessary to thin the woodlot at two years as recommended. She kept harvesting the poles depending on the sizes required by the customers. The twigs and branches left after pole harvesting were then used for firewood.

(g) Multiple tree species in a woodlot

In the same woodlot, case 12 from Namabya integrated *Eucalyptus grandis*, *Melia volkensii* and *Neolamarckia cadamba*. When asked why she made such a mixture, the case emphasized that mixing different tree species would enable the household to get several tree products at other times: *"I will keep harvesting the Eucalyptus for firewood and poles while allowing Melia volkensii and Neolamarckia cadamba to grow for timber"*. This was contrary to the recommended use of a single tree species (monoculture), which supposedly simplifies management. However, the case demonstrated his reasoning behind establishing a multiple tree species woodlot. The tree species were planted haphazardly, and it was clear that the case was knowledgeable about the growth rates and appropriateness of the individual tree species for particular products. The short maturity period of eucalyptus (3-4 years) ensured that fuelwood and poles could be harvested in the short term.

In contrast, the extended maturity of *Melia volkensii* and *Neolamarckia cadamba* meant that they would be kept in the plot for timber in the future. Although single tree species in woodlots ease tree management and enhance performance (Ndayambaje et al. 2013), the mixed species woodlot, in this case, seemingly performed well for the case. This observation contradicted other studies highlighting that multiple tree species tend to outcompete each other (Yoshida and Kamitani 2000; Marron et al. 2018; Marron and Epron 2019). The enhanced performance of the mixed tree species, in this case, could be alluded to a clear objective and efforts by the case to ensure appropriate management practices of each tree species. The species, too, proved to be compatible. Recent studies have demonstrated that tree species' mixtures provide additional benefits over monoculture-based woodlots (Vigulu et al. 2017; Liu et al. 2018; Le et al. 2020). This case's tree species mixture seemed to be working well, whether by luck or not, but other mixtures may not work. For more sustained benefits from the practice of using tree species combinations in a woodlot, users should be knowledgeable of their growth habits and interaction outcomes. Some tree species that outcompete others for light and soil nutrients (Muhammed 2019) may give a disappointing outcome that may demotivate uptake and scaling-up of agroforestry technologies.

Space optimizing practices

The land is probably the most limiting factor of agricultural production for smallholder farmers, especially in Uganda's eastern highlands. That requires creativity in using available limited land to achieve multiple household needs. To achieve their household needs and aspirations, some cases devised their practices to optimize the use of little space/land available for farming.

(a) Using agroforestry trees to support climbing plants under intercropping

Among the 4 cases that were selected under intercropping technology, case 9 (a youth female) used the space around his trees of *Neolamarkhia cadamba* she had initially planted in the coffee garden for firewood and shade, to integrate climbing yams (*Dioscorea* spp) locally known as "balugu". This is a practice she learned while growing up in the central region as she explains, *"My aunt used to plant these yams on every tree in her garden. We used to feed on them, especially during breakfast. But now they are marketable when you visit Manafwa town in the evening, the women prepare and sell them as food"*. She not only cultivated yams for food but also sold some for income. Climbing yams perform well in any soil as long as they have a stake or support in which to climb. This practice of integrating climbing yams as a companion crop on the trees increased the intercropping technology's useability in ensuring food security and supporting income. Studies stress the importance of companion planting in buffering failure in the main crop enterprises (Gwynn-Jones et al., 2018; Kebede et al., 2018; Khan et al., 2014).

(b) Integrating cocoa yams in the woodlot

Case 11 had devised growing cocoa yams in the woodlot, similar to the popular taungya system practised in plantation forestry (Appiah et al., 2020). The plot where the woodlot had been established could experience seasonal water-logging following heavy rains. This practice, according to the case, was based on what the case had learned during a visit to a friend as narrated: *"When I visited my friend in Mbale, I noticed that the cocoa yams he had planted under his eucalyptus trees were growing well. I also decided to plant cocoa yams in my eucalyptus woodlot"*. Although the case cultivated other crops on his farm, he anticipated that yams could grow in the small gaps between trees in the woodlot. The integration of yams in the woodlot meant that the case had to weed them. In weeding the cocoa yams, the trees in the woodlot were also indirectly weeded. This aligns well with the literature that indicates that farmers tend to focus on crop enterprises instead of frees whose returns are not envisaged in the short-term future (Ndayambaje et al., 2013).

(c) **Relayed planting of eucalyptus trees in the woodlot**

Case 10 (a male youth) planted eucalyptus seedlings at different times in the same plot (relay planting), creating an uneven-aged eucalyptus stand. Being a tree seedling distributor in the community, the readily available free seedlings from the T4FS project also ensured that he planted more and more eucalyptus at different seasons in the same plot. Being a male youth, this case was probably more oriented to income generation. Having trees of different ages in the woodlot allowed him to harvest continuously for income generation, as affirmed by the case: *When I harvest older ones for firewood and poles, I create space for the young trees to grow.* The case's assertion is probably true since harvesting mature bigger trees opens the canopy for the young ones. But in case the young ones are stunted, they may still fail to regain vigour. Direct observations showed that despite the seemingly mature trees' harvest, the remaining ones were overcrowded with varying sizes and ages. There was hardly space for the young trees to gain size over time apart from etiolation in some and stuntedness in others. Studies show that when trees get stunted early due to competition, they hardly regain vigour (Sharma et al. 2016; Bassil et al. 2019), consequently affecting the quality and quantity of firewood and poles harvested. When appropriately used, relay planting should improve the benefits of continuous harvesting of quality trees for home use and income. Inappropriate use, however, is likely to demoralize uptake given the compromised expected benefits.

Production Cost-minimizing modifications and practices

In agribusiness, the cost of production is one factor that encourages or discourages using some technologies. Weeding and removing tree stumps later make agroforestry an expensive venture. After some time, tree stumps from cut trees in the field/garden become a menace, and this can especially be a big problem in plots with woodlots.

(a) **Close spacing to reduce stump sizes in the woodlot**

Case 9 had a plot that occasionally flooded, making it difficult to grow crops. Based on the widespread belief that Eucalyptus could survive and drain the water in such a plot, the case planted Eucalyptus. The case had hope that once Eucalyptus had helped to drain water, the plot would be used for other crops in the future. From the experience of crowded plants' tendency to grow smaller, she used close spacing (1m x 1m) to establish a eucalyptus woodlot. The case intended to produce firewood and poles from the woodlot. Closer spacing would enable the case to (1) suppress weeds, (2) have many stems of moderate size which would not need splitting as commonly done for big logs, and (3) retain small stumps that could easily be removed in future to pave the way for alternative land uses. The case herself emphasised these: *"When I reduced the recommended spacing from 3m x 3m to 1m x 1m, I ended up weeding less, harvesting more good-sized trees for fuelwood. As a result, I will spend less on removing the stumps when preparing the plot for a different crop"*. As articulated, the practice helped the case to reduce production costs. Smaller stumps from small trees would be easier to dig out and take less time and labour than bigger ones.

Whereas close spacing could help smallholder farmers suppress weeds and reduce stump sizes, the practice can only be appropriate for woodlots managed for firewood. If used in timber-managed woodlots, close spacing can intensify competition between trees, hindering them from attaining optimal timber sizes. Studies on timber production show that low-density woodlots offer higher economic returns than high-density stands (Hébert et al. 2016; Rais et al. 2020). A related study in the Solomon Islands revealed that in the early stages of establishment, the Mean Annual Increment (MAI) was highest in closely spaced treatments but gradually decreased below wider spacing in the later stages (Vigulu et al. 2019). The decreasing MAI was attributed to the onset of growth suppression, which arose from close spacing. To achieve the smallholder farmers' ultimate timber objective, densely established woodlots require timely thinning. Unfortunately, smallholder farmers in Uganda's Mt. Elgon region rarely thinned their woodlots on time.

Figure 4.4: Close spacing used in the eucalyptus woodlot

Time shortening modifications and practices

Trees take a long time to deliver the anticipated products and services. To reduce the waiting time for tree products, cases 4 modified the boundary technology while cases 6 and 7 devised a practice.

(a) Reduced spacing and cutting height of calliandra for fodder in the boundary planting technology

Case 4 reduced the spacing and cutting height of *Calliandra calothyrsus* for fodder from the recommended 60 cm to 30 cm and 50 cm to 20 cm, respectively, as she explains: *"I decided to harvest my Calliandra at the height of 20 cm because, from my experience, this enabled it to sprout more so that I can get more fodder for my cows"*. This seemed to work for the case even as some studies show that the cutting height of *Calliandra calothyrsus* for fodder ranges from 50 cm to 100 cm depending on the frequency and intra-row spacing (Kabi and Bareeba 2008; Widyati et al. 2019; Fungo et al. 2020; Patric et al. 2020). A smaller spacing seems to be supported by Fungo et al. (2020), who reported a 20% reduction in *Calliandra calothyrsus* forage biomass for wider spacing. Thus, reducing spacing to 30 cm and cutting height to 20 cm, which were less than the recommended treatments, might have resulted in the higher biomass observed by the case.

(b) Injuring of fruit trees to induce early and high yielding

Cases 6 and 7 induced fruiting by injuring Avocado trees. However, the practice was performed somewhat differently. Case 6 injured the back of Avocado trees by cutting it several times using a panga, while case 7 drove a nail through the heartwood of each avocado tree. Both cases explained that practice quickens and enhances fruiting. The practice of injuring trees has been previously used in defoliation to stress the tree and trigger flowering (Devi et al., 2019; Malik, Perez, & Kunta, 2015; Pastore et al., 2013). However, this seemingly good practice can also result in injured points serving as entry points for pests and diseases (Alves & Nunes, 2017; Zhang et al., 2018). Although there was no evidence of pests and diseases on the avocado trees under this study, this practice needs to be improved by documenting proper procedures that can be followed to ensure that the practice is not a source of diseases and pests.

4.4 Conclusion

This study examined how smallholder farmers adjusted the experts 'recommendations and devised their own practices to fit the agroforestry technologies to their contexts. Regardless of age and sex, cases either modified or used their practices to enhance the technologies' useability to their context. These modifications and practices were categorized as seedling survival enhancing, benefit diversifying, space optimizing, production cost-minimizing, and time shortening. As highlighted by the cases, most of the changes made to the recommended technologies and own practices had profound anticipated advantages to the household and underlying implications to farm productivity, which was not noticeable. The agroforestry's long-term nature made it risky for smallholder farmers to forego their limited spaces for food production favouring trees (agroforestry). The cases highlighted the importance of identifying possibilities to accrue short-term benefits from trees in making agroforestry technologies more useful in smallholder farmers' resource-constrained contexts. Therefore, the modifications and practices identified in this study must be incorporated in the participatory research and development agenda so that positive and negative implications can be teased out for the smallholder farmers to make informed decisions.

We argue that smallholder farmers' technology utilization involves contextual readjustments that should not simply be ignored. Instead, agroforestry promoters need to embrace smallholder farmers' modifications and use some to reinvent technologies with enhanced benefits. This will increase agroforestry technologies' likelihood of uptake and diffusion into the farming community for broader impact. The linear model of technology transfer commonly applied in agroforestry dissemination favours blueprints that often do not work wholesomely for smallholder farmers. Therefore, there is a need to rethink the linear technology transfer model to provide space for much-needed feedback.

This study has demonstrated that farmers are active adopters capable of processing experts' messages and coming up with modifications to suit their circumstances. They evaluate the technologies and, if need be, modify them to come up with what addresses issues they are confronted with. For instance, this study has shown that in their endeavour to rotate crops in different crops, farmers in the eastern highlands found the use of wide spaces in woodlots to promote weeds and make the woodlot technology quite laborious. As a result, some use narrow spacing in woodlots which ensures faster canopy closure to suppress the weeds. This highlights the need for researchers to work closely with smallholder farmers to capture strategies they come up with in their everyday farming life. Such strategies can then serve as feedback into the research and development system. If such an approach that promotes farmers' and scientists' interactions is sustained, it may encourage the development of technologies responsive to farmers' needs.

In this study, I have documented smallholder farmers' modifications and discussed the reasons for these modifications. Although the sample was not adequate for generalizing the findings, the study was anchored in real-life situations and offered a rich and holistic account of smallholder farmers' modifications that enable them to adapt and make agroforestry technologies more applicable to their contexts. More research needs to be done to evaluate smallholder farmers' modifications as a basis for promoting them for wide-scale uptake of agroforestry.

References

Alves, S., & Nunes, C. C. (2017). Seasonal susceptibility of apple trees to Neonectria ditissima wound infections. *New Zealand Plant Protection*, *70*, 73–77. https://doi.org/10.30843/nzpp.2017.70.30

Amazonas, N. T., Forrester, D. I., Silva, C. C., Almeida, D. R. A., Rodrigues, R. R., & Brancalion, P. H. (2018). High diversity mixed plantations of Eucalyptus and native trees: An interface between production and restoration for the tropics. *Forest Ecology and Management*, *417*, 247–256. https://doi.org/10.1016/j.foreco.2018.03.015

Appiah, M., Yeboah, B., Yeboah, M. A., & Danquah, J. A. (2020). Community Experiences in the use of Modified Taungya System for Restoring Degraded Forests and Improving Livelihoods in Ghana. *Environmental Management and Sustainable Development*, *9*(3), 1. https://doi.org/10.5296/emsd.v9i3.17047

Bassil, S., Nyland, R. D., Kern, C. C., & Kenefic, L. (2019). Dynamics of the diameter distribution after selection cutting in uneven-aged and even-aged northern hardwood stands: a long-term evaluation. *Canadian Journal of Forest Research*, *49*(12).

Bauw, P. de, van Asten, P. [P.], Jassogne, L. [L.], & Merckx, R. (2016). Soil fertility gradients and production constraints for coffee and banana on volcanic mountain slopes in the East African Rift: A case study of Mt. Elgon. *Agriculture, Ecosystems & Environment*, *231*, 166–175. https://doi.org/10.1016/j.agee.2016.06.036

Benjamin, E. O. (2020). Smallholder Agricultural Investment and Productivity under Contract Farming and Customary Tenure System: A Malawian Perspective. *Land*, *9*(8), 277. https://doi.org/10.3390/land9080277

Bunge, M. (1974). Technology as Applied Science. In F. Rapp (Ed.), *Contributions to a Philosophy of Technology* (pp. 19–39). Dordrecht: Springer Science+Business Media B.V. https://doi.org/10.1007/978-94-010-2182-1_2

Cedamon, E., Nuberg, I., Pandit, B. H., & Shrestha, K. K. (2018). Adaptation factors and futures of agroforestry systems in Nepal. *Agroforestry Systems*, *92*(5), 1437–1453. https://doi.org/10.1007/s10457-017-0090-9

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (Third Edition). London, United Kingdom: Sage Publications. Retrieved from http://www.drbrambedkarcollege.ac.in/sites/default/files/research-design-ceil.pdf

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, *11*, 100. https://doi.org/10.1186/1471-2288-11-100

Devi, N. A., Arulmozhiyan, R., & Balamohan, N. T. (2019). Induction of off-season flowering in mango through farmer's participatory research in Krishnagiri district under NAIP. *Journal of Pharmacognosy and Phytochemistry*, *8*(5), 2466–2471.

Doddabasawa, Chittapur, B. M., & Mahadeva Murthy, M. (2020). Economics and energy potential of traditional agroforestry systems under contrasting ecosystems in semi arid tropics. *Agroforestry Systems*. Advance online publication. https://doi.org/10.1007/s10457-020-00545-y

Epila, J., Verbeeck, H., Otim-Epila, T., Okullo, P., Kearsley, E., & Steppe, K. (2017). The ecology of *Maesopsis eminii* Engl. in tropical Africa. *African Journal of Ecology*, *55*, 679–692.

Fritzen-Pedicini, C., Bleasdale, S. C., Brosseau, L. M., Moritz, D., Sikka, M., Stiehl, E., & Jones, R. M. (2019). Utilising the focused conversation method in qualitative public health research: A team-based approach. *BMC Health Services Research*, *19*(1), 306. https://doi.org/10.1186/s12913-019-4107-0

Fungo, B., Buyinza, J., Sekatuba, J., Nansereko, S., Ongodia, G., Kwaga, P., . . . Agaba, H. (2020). Forage biomass and soil aggregate carbon under fodder banks with contrasting management regimes. *Agroforestry Systems*, *94*(3), 1023–1035. https://doi.org/10.1007/s10457-019-00473-6

Giller, K. E. [K. E.], Tittonell, P. [P.], Rufino, M. C., van Wijk, M. T., Zingore, S., Mapfumo, P., . . . Vanlauwe, B. [B.] (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems*, *104*, 191–203.

Glover, D., Venot, J. P., & Harro, M. (2017). On the Movement of Agricultural Technologies. *Agronomy for Development: The Politics of Knowledge in Agricultural Research*, *14*.

Gomez y Paloma, S., Riesgo, L., & Louhichi, K. (Eds.) (2020). *The role of smallholder farms in food and nutrition security*. Cham, Switzerland: Springer.

Gwynn-Jones, D., Dunne, H., Donnison, I., Robson, P., Sanfratello, G. M., Schlarb-Ridley, B., . . . Convey, P. (2018). Can the optimisation of pop-up agriculture in remote communities help feed the world? *Global Food Security*, *18*, 35–43. https://doi.org/10.1016/j.gfs.2018.07.003

Hébert, F., Krause, C., Plourde, P.-Y., Achim, A., Prégent, G., & Ménétrier, J. (2016). Effect of Tree Spacing on Tree Level Volume Growth, Morphology, and Wood Properties in a 25-Year-Old Pinus banksiana Plantation in the Boreal Forest of Quebec. *Forests*, *7*(12), 276. https://doi.org/10.3390/f7110276

Hockett, M., & Richardson, R. B. (2018). Examining the drivers of agricultural experimentation among smallholder farmers in Malawi. *Experimental Agriculture*, *54*(1), 45–65. https://doi.org/10.1017/S0014479716000673

IFAD and UNEP (2013). Smallholders, food security and the environment. Rome: International Fund for Agricultural Development, 29.

Joel Buyinza, Ian K. Nuberg, Catherine (2020). Assessing smallholder farmers' motivation to adopt agroforestry using a multi-group structural equation modeling approach. *Agroforestry Systems*, *94*, 2199–2211.

Kabi, F., & Bareeba, F. B. (2008). Herbage biomass production and nutritive value of mulberry (Morus alba) and Calliandra calothyrsus harvested at different cutting frequencies. *Animal Feed Science and Technology*, *140*(1-2), 178–190. https://doi.org/10.1016/j.anifeedsci.2007.02.011

Kabiru, S., Hassan, S., Umar, U. A., & Musab, I. (2017). An Inventory of Agroforestry Practices in Butta Sub-County, Manafwa District, Uganda. *Asian Journal of Environment & Ecology*, *5*(4), 1–7.

Karshie, E. A., Ajayi, O. V., Gideon, P. K., Bulus, J., & Mtomga, N. B. (2017). Farmers' participation in agroforestry practices in Taraba State, Nigeria: n Analysis of benefits. *Greener Journal of Agricultural Sciences*, *7*(8), 182–188.

Kebede, Y., Baudron, F. [Frédéric], Bianchi, F., & Tittonell, P. [Pablo] (2018). Unpacking the push-pull system: Assessing the contribution of companion crops along a gradient of landscape complexity. *Agriculture, Ecosystems & Environment*, *268*, 115–123. https://doi.org/10.1016/j.agee.2018.09.012

Khalil, C. A., Conforti, P., Ergin, I., & Gennari, P. (2017). *Defining smallscale food producers to monitor target 2.3 of the 2030 agenda for sustainable development* (Working paper series No. ESS/17-12). Retrieved from Food and Agriculture Organisation of the United Nations website: http://www.fao.org/3/a-i6858e.pdf

Khan, Z. R., Midega, C. A. O., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J. A., & Pickett, J. A. (2014). Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *369*(1639), 20120284. https://doi.org/10.1098/rstb.2012.0284

Kummer, S., Leitgeb, F., & Vogl, C. R. (2016). Farmers' Own Research: Organic Farmers' Experiments in Austria and Implications for Agricultural Innovation Systems. *Sustainable Agriculture Research*, *6*(1), 103. https://doi.org/10.5539/sar.v6n1p103

Le, H. D., Smith, C., Herbohn, J., & Nguyen, H. (2020). A Comparison of Growth, Structure and Diversity of Mixed Species and Monoculture Reforestation Systems in the Philippines. *Journal of Sustainable Forestry*, 1–30. https://doi.org/10.1080/10549811.2020.1767145

Leeuwis, C., & Van den Ban, A. (2004). *Communication for Rural Innovation: Rethinking Agricultural Extension* (3rd Edition). Oxford OX4 2DQ, UK: Blackwell Science Ltd.

Liu, C. L. C., Kuchma, O., & Krutovsky, K. V. (2018). Mixed-species versus monocultures in plantation forestry: Development, benefits, ecosystem services and perspectives for the future. *Global Ecology and Conservation*, *15*, e00419. https://doi.org/10.1016/j.gecco.2018.e00419

Livesley, S. J., Gregory, P. J., & Buresh, R. J. (2000). Competition in tree row agroforestry systems. 1. Distribution and dynamics of fine root length and biomass. *Plant and Soil*, *227*(1/2), 149–161. https://doi.org/10.1023/A:1026551616754

Lowder, S. K., Skoet, J., & Raney, T. (2016). The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Development*, *87*, 16–29. https://doi.org/10.1016/j.worlddev.2015.10.041

Malik, N. S., Perez, J. L., & Kunta, M. (2015). Inducing Flushing in Citrus Cultivars and Changes in Polyphenols Associated With Bud Break and Flowering. *Journal of Horticulture*, *2*(3).

Marron, N., & Epron, D. (2019). Are mixed-tree plantations including a nitrogen-fixing species more productive than monocultures? *Forest Ecology and Management*, *441*, 242–252. https://doi.org/10.1016/j.foreco.2019.03.052

Marron, N., Priault, P., Gana, C., Gérant, D., & Epron, D. (2018). Prevalence of interspecific competition in a mixed poplar/black locust plantation under adverse climate conditions. *Annals of Forest Science*, *75*(23). https://doi.org/10.1007/s13595-018-0704-z

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. Revised and Expanded from "Case Study Research in Education. San Francisco, CA: Jossey-Bass Publishers.

Mucheru-muna, M., Mugendi, D., Pypers, P., Mugwe, J., Kung'u, J., Vanlauwe, B., & Merckx, r. (2014). enhancing maise productivity and profitability using organic inputs and mineral fertilizer in central kenya small-hold farms. *Experimental Agriculture*, *50*(2), 250–269. https://doi.org/10.1017/S0014479713000525

Muhammed, T. (2019). Tree-Crop Interaction Management in Agroforestry: A Review. *Journal of Ecology and Natural Resources*, *3*(5). Retrieved from https://medwinpublishers.com/JENR/JENR16000180.pdf

Muir, J. (2019). Leguminous forage shrubs: the underutilised canopy. *The Journal of International Legume Society*. (17). Retrieved from http://www.ias.csic.es/grainlegumesmagazine/legum_perspect_17.pdf

Mulyono, A., Arisbaya, I., & Sudrajat, Y. (2020). Imaging Tree Root Zone Geometry Using Electrical Resistivity Tomography. *RISET Geologi Dan Pertambangan*, *30*(1), 55–64. https://doi.org/10.14203/risetgeotam2020.v30.1048

Muthuri, C. W., Mukuralinda, A., Abayneh, D., Okia, C., Buyinza, J., Hadgu, K., . . . Sinclair, F. (2017). *Improving sustainable productivity in farming systems and enhanced livelihoods through adoption of evergreen agriculture in eastern Africa shortened as 'Trees for food security' project (T4FS): Final report*. Canberra ACT 2601, Australia.

Nair, P. K. R. (1993). *An introduction to agroforestry*. Dordrecht, Boston: Kluwer Academic Publishers in cooperation with International Centre for Research in Agroforestry.

Nair, P. K. R. (2011). Directions in tropical agroforestry research: past, present, and future. In P. K. R. Nair & C. R. Latt (Eds.), *Forestry Sciences: v. 53. Directions in tropical agroforestry research* (Vol. 53, pp. 223–245). Dordrecht, London: Springer. https://doi.org/10.1007/978-94-015-9008-2_10

Namey, E., Guest, G., Thairu, L., & Johnson, L. (2008). Data reduction techniques for large qualitative data sets. *Handbook for Team-Based Qualitative Research*, *2*(1), 137–161.

Ndayambaje, J. D., Heijman, W. J. M., & Mohren, G. M. J. (2013). Farm woodlots in rural Rwanda: purposes and determinants. *Agroforestry Systems*, *87*(4), 797–814. https://doi.org/10.1007/s10457-013-9597-x

Okia, C., Buyinza, J., Agaba, H., Muthuri, C., Kiptot, E., Kinuthia, R., . . . Sinclair, F. (2016). *Trees for food security project: A glimpse of Uganda*. Retrieved from World Agroforestry Centre website: https://www.worldagroforestry.org/sites/default/files/outputs/Okia%20et%20al%2C%202016.%20Trees%20for%20Food%20Security%20Project%2C%20A%20Glimpse%20of%20Uganda-%20Magazine-%20WP%203.pdf

Omona, J. (2013). Sampling in Qualitative Research: Improving the Quality of Research Outcomes in Higher Education. *Makerere Journal of Higher Education*, *4*(2). https://doi.org/10.4314/majohe.v4i2.4

Oyana, T. J., Kayendeke, E., Bamutaze, Y., & Kisanga, D. (2015). A field assessment of land use systems and soil properties at varied landscape positions in a fragile ecosystem of Mount Elgon, Uganda. *African Geographical Review*, *34*(1), 83–103. https://doi.org/10.1080/19376812.2014.929970

Owori, M. (2020). Poverty in Uganda: National and regional data and trends. Development Initiatives. https://devinit. org/resources/poverty-uganda-national-and-regional-data-and-trends.

Pastore, C., Zenoni, S., Fasoli, M., Pezzotti, M., Tornielli, G. B., & Filippetti, I. (2013). Selective defoliation affects plant growth, fruit transcriptional ripening program and flavonoid metabolism in grapevine. *BMC Plant Biology*, *13*(30).

Patric, A., Raj, A. K., Kunhamu, T. K., Jamaludheen, V., & Santhoshkumar, A. V. (2020). Productivity-of-tree-fodder-banks-in-a-typical-homegarden-of-Central-Kerala. *Indian Journal of Agroforestry*, *22*(1), 17–23.

Qiao, X., Sai, L., Chen, X., Xue, L., & Lei, J. (2019). Impact of fruit-tree shade intensity on the growth, yield, and quality of intercropped wheat. *PloS One*, *14*(4), e0203238. https://doi.org/10.1371/journal.pone.0203238

Qin, F., Liu, S., & Yu, S. (2018). Effects of allelopathy and competition for water and nutrients on survival and growth of tree species in Eucalyptus urophylla plantations. *Forest Ecology and Management*, *424*, 387–395. https://doi.org/10.1016/j.foreco.2018.05.017

Rahn, E., Liebig, T., Ghazoul, J., van Asten, P. [Piet], Läderach, P., Vaast, P., . . . Jassogne, L. [Laurence] (2018). Opportunities for sustainable intensification of coffee agro-ecosystems along an altitudinal. *Agriculture, Ecosystems & Environment*, *263*, 31–40.

Rais, A., Poschenrieder, W., van de Kuilen, J.-W. G., & Pretzsch, H. (2020). Impact of spacing and pruning on quantity, quality and economics of Douglas-fir sawn timber: scenario and sensitivity analysis. *European Journal of Forest Research*, *139*(5), 747–758. https://doi.org/10.1007/s10342-020-01282-8

Ramachandran Nair, P. K. (2007). Agroforestry for Sustainability of Lower-Input Land-Use Systems. *Journal of Crop Improvement*, *19*(1-2), 25–47. https://doi.org/10.1300/J411v19n01_02

Rogers, E. M. (2010). *Diffusion of innovations* (4th Edition). New York: Simon and Schuster.

Roo, N. D., Andersson, J. A., & Krupniks, T. J. (2019). On-farm trials for development impact? the organisation of research and the scaling of agricultural technologies. *Experimental Agriculture*, *55*(2), 163–184. https://doi.org/10.1017/S0014479717000382

Rubba, P. A., & Harkness, W. L. (1993). Examination of Preservice and In-service Secondary Science Teachers' Beliefs about Science-Technology-Society Interactions. *Science Education*, *77*(4), 407–431. Retrieved from https://eric.ed.gov/?id=ej484123

Ryan, G. W., & Bernard, H. R. (2000). *Techniques to identify themes in qualitative data*. Handbook of Qualitative Research (2nd ed.). Thousand Oaks, CA: Sage Publications.

Scoones, I. (2009). Livelihoods perspectives and rural development. *The Journal of Peasant Studies*, *36*(1), 171–196. https://doi.org/10.1080/03066150902820503

Sharma, A., Bohn, K., Jose, S., & Dwivedi, P. (2016). Even-Aged vs. Uneven-Aged Silviculture: Implications for Multifunctional Management of Southern Pine Ecosystems. *Forests*, *7*(12), 86. https://doi.org/10.3390/f7040086

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage Publications.

Swain, J. M., & Spire, Z. D. (2020). The role of informal conversations in generating data, and the ethical and methodological issues they raise, *21*(1). https://doi.org/10.17169/FQS-21.1.3344

Tafere, S. M., & Nigussie, Z. A. (2018). The adoption of introduced agroforestry innovations: determinants of a high adoption rate – a case-study from Ethiopia. *Forests, Trees and Livelihoods*, *27*(3), 175–194. https://doi.org/10.1080/14728028.2018.1493954

Tambo, J. A., & Wünscher, T. (2017). Farmer-led innovations and rural household welfare: Evidence from Ghana. *Journal of Rural Studies*, *55*, 263–274. https://doi.org/10.1016/j.jrurstud.2017.08.018

Tambo, J. A., & Wünscher, T. (2018). Building farmers' capacity for innovation generation: Insights from rural Ghana. *Renewable Agriculture and Food Systems*, *33*(2), 116–130. https://doi.org/10.1017/S1742170516000521

Tayebwa (2013). *East African Community youth policy*. EAC Secretariat. Retrieved from http://meac.go.ke/wp-content/uploads/2017/03/EAC-Youth-Policy.pdf

UNDP (2013). *Ecosystem based adaptation in mountain Elgon ecosystem*. Vulnerability Impact Assessment (VIA) for the Mt Elgon Ecosystem. Kampala Uganda. Retrieved from United Nations Development Programme website: https://www.adaptation-undp.org/sites/default/files/downloads/undp_ugandaunepunep-wcmc_2013_uganda_via_report.pdf

Van der Veen, M. (2010). Agricultural innovation: invention and adoption or change and adaptation? *World Archaeology*, *42*(1), 1–12.

Vanlauwe, B. [Bernard], Coe, R., & Giller, K. E. [Ken E.] (2016). Beyond the averages: new approaches to understand heterogeneity and risk of technology success or failure in smallholder farming. *Expl Agric.*, *55*(1), 84–106.

Vedeld, P., Cavanagh, C., Petursson, J., Nakakaawa, C., Moll, R., & Sjaastad, E. (2016). The political economy of conservation at mount elgon, Uganda: Between local deprivation, regional sustainability, and global public goods. *Conservation and Society*, *14*(3), 183. https://doi.org/10.4103/0972-4923.191155

Vigulu, V. W., Blumfield, T. J. [T. J.], Reverchon, F. [F.], Xu, Z. H., & Tutua, S. S. (2017). Competition for nitrogen between trees in a mixed-species plantation in the Solomon Islands. *Australian Forestry*, *80*(3), 135–142. https://doi.org/10.1080/00049158.2017.1326093

Vigulu, V., Blumfield, T. J. [Timothy J.], Reverchon, F. [Frédérique], Hosseini Bai, S., & Xu, Z. (2019). Growth and yield of 5 years old teak and flueggea in single and mixed species forestry systems in the Solomon Islands. *New Forests*, *50*(4), 629–642. https://doi.org/10.1007/s11056-018-9684-y

Viswanath, S., & Lubina, P. A. (2017). Traditional Agroforestry Systems. In J. C. Dagar & V. P. Tewari (Eds.), *Agroforestry: Anecdotal to modern science / edited by Jagdish Chander Dagar, Vindhya Prasad Tewari* (pp. 91–119). Singapore: Springer Singapore : Imprint : Springer. https://doi.org/10.1007/978-981-10-7650-3_3

Widyati, E., Darwiati, W., & Yulianti, M. (2019). Land Management in Optimizing Productivity of Limited Land to Deal with Rural Food, Feed and Fuel (3F) Security. *IOP Conference Series: Earth and Environmental Science*, *394*, 12068. https://doi.org/10.1088/1755-1315/394/1/012068

Wolfenson, K. D. M. (2013). Coping with the food and agriculture challenge: smallholders' agenda. Food and Agriculture Organisation of the United Nations, Rome.

Yazan, B. (2015). Three Approaches to Case Study Methods in Education: Yin, Merriam, and Stake. *The Qualitative Report*, *20*(2), 134–152. Retrieved from http://www.nova.edu/ssss/QR/QR20/2/yazan1.pdf

Yin, R. K. (2018). *Case study research and applications: Design and methods* (Sixth edition). Los Angeles: SAGE.

Yoshida, T., & Kamitani, T. (2000). Interspecific competition among three canopy-tree species in a mixed-species even-aged forest of central Japan. *Forest Ecology and Management*, *137*, 221–230.

Zhang, L., Koc, A. B., Wang, X. N., & Jiang, Y. X. (2018). A review of pruning fruit trees. *IOP Conference Series: Earth and Environmental Scienceci._153_062029*, *153*(6).

CHAPTER FIVE

SYNTHESIS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter of the dissertation presents the main findings' synthesis and draws the main conclusions and recommendations to policy, practice and research. The chapter also highlights the contribution to existing knowledge and implications for future research.

This study was prompted by the need to understand how smallholder farmers adapted agroforestry technologies (their choices, utilisation, modifications and practices) to make them more useful to their contexts. The interest in studying agroforestry technologies' adaptation emerged from the author's previous engagement in development research in agroforestry among smallholder farmers in Uganda's eastern highlands. During the engagement, it was realised that despite trying to persuade smallholder farmers to implement agroforestry technologies in scientifically recommended ways to increase their fields' productivity, they made different choices and adjusted the technologies to suit their contexts. The focus then was on the need to have smallholder farmers take up agroforestry technologies to scale-out agroforestry. However, there was an apparent need to understand the rationale behind their choices, utilisation, and modifications and practices they were undertaking to increase agroforestry's usability to their livelihoods.

Smallholder farmers in the eastern highlands of Uganda are faced with many challenges about their livelihoods, including food and nutrition insecurity. They prefer agricultural technologies that translate quickly into outcomes to abate such challenges. Their motivations to integrate agroforestry technologies which are long-term on their small land parcels, cannot be under-estimated. With agroforestry technologies, farmers need at least two years before realising benefits from the trees. Therefore, when smallholder farmers adapt agroforestry technologies in ways they presume to increase their useability, such methods need to be examined and, where applicable, mainstreamed into research and extension efforts.

5.2 Revisiting the context and objectives of the study

Smallholder farmers in the eastern highlands of Uganda, despite being a significant force in the country's agricultural sector, continue to experience dwindling farm productivity – putting many at livelihood survival risks related to food and nutritional insecurity (Tendall et al., 2015).

Agroforestry offered a cheap and sustainable approach to stabilise smallholder farm productivity in the eastern highlands. Agroforestry can increase farm productivity directly by providing food (fruits) and other tree products such as firewood, poles, medicine, and timber, which can be used domestically or sold to generate income for smallholder families. Indirectly, agroforestry can enhance soil conservation, replenish fertility, provide a microclimate for improved crop performance, and mitigate climate change. However, the promotion of agroforestry technologies among smallholder farmers required a change from business as usual to its implementation in a scientifically proven way if the desired farm productivity outcomes were to be realised (Dagar & Tewari, 2017). Thus, state and non-state agencies in the region started working together to promote scientifically proven agroforestry technologies that were seemingly appropriate for smallholder farmers. How agroforestry technologies are unpacked and grounded in particular spaces and contexts (adaptation) of smallholder farmers has received little attention in the promotion efforts. Adaptation is critical in overcoming barriers to use and scaling out of agroforestry technologies (Anderson, 1993; Cedamon et al., 2018; Kmoch et al., 2018). In this study, adaptation was operationalised as the choice, use, modification, and own practices used by smallholder farmers contrary to their original design and specifications to make agroforestry technologies more useful to their livelihoods. Smallholder farmers who have not chosen a technology cannot adapt it. Thus, adaptation decisions are conditional upon having chosen a technology. The general objective of this study was to establish the rationale for smallholder farmers' choices and utilisation and the modifications and practices they use to adapt agroforestry technologies to their contexts in the eastern highlands of Uganda. At the outset of this study, it was assumed that adaptation of agroforestry technologies by smallholder farmers is a function of the socio-technological context and intra-household decision-making (Acosta et al., 2019; Ronner et al., 2018). Three objectives were developed for this study: 1) determine the influence of the socio-technological factors on smallholder farmers' choices of agroforestry technologies for adaptation, 2) examine the influence of intra-household decision-making on the use, and 3) describe the smallholder farmers' modifications and own practices in the utilisation of the agroforestry technologies for improved farm productivity. Addressing these objectives provides a useful summary critical to understanding smallholder farmers' adaptations of agroforestry technologies in Uganda's eastern highlands.

5.3 Synthesis

Results in Chapter 2 indicate that the most critical socio-technological factors influencing smallholder farmers' choices of agroforestry technologies were perceived value of the technology, peer influence and smallholder farmers' perception of own ability (perceived behavioural control). Contrary to the literature on uptake of agricultural technologies, ease of use and technology compatibility with existing practices did not significantly influence smallholder farmers' choice of agroforestry technology. This is because the sample was drawn from smallholder farmers who had already been exposed to the technologies by participating in agroforestry training sessions, on-farm trials and demonstrations. The technology's perceived value was the only factor influencing the choice probability of all the three agroforestry technologies under study (boundary planting, intercropping and woodlot). The importance of perceived value as an enabler for smallholder farmers to use new technologies has been highlighted in many studies (Brown et al., 2017; Li et al., 2020). In the context of this study, perceived value is the positive evaluation of a given technology based on comparing its benefits and disadvantages with the alternatives (Wang & Wang, 2010). Smallholder farmers are rational and tend to choose what is best for them from the available options. Food security, income and health are vital for household members' wellbeing (Ceballos et al., 2020; Kahane et al., 2013). The values smallholder farmers perceive of agroforestry are informed by its multiple benefits in terms of environmental services (such as soil fertility enhancement, land rehabilitation, microclimate amelioration), social benefits (e.g. food and nutritional security, herbal medicine and cultural practices) and economic benefits (e.g. diversified source of income). However, agroforestry has also increased the farming system's complexity (Burgess et al., 2016). This means that farm management and planning decisions become more critical in determining the agroforestry technologies' performance. For instance, while the introduction of trees in the cropping system can provide an additional source of future revenue from timber, trees can also compete with crops for light, soil water and nutrients (Ndoli et al., 2017; Van Noordwijk et al., 2015). Consequently, smallholder farmers need to make several considerations in their decision-making processes. These considerations inform smallholder farmers' intra-household decision-making (Chapter 3).

Results in chapter 3 show that male decision-makers in dual-headed households dominate intra-household decision-making in pre-production, production and post-production phases of agroforestry technology utilisation. Several studies have indicated that males are the primary decision-makers in a dual-headed household (Alwang et al., 2017; Singh et al., 2016). This dominance of males in decision-making in the study area is premised on the fact that they are the principal owners of the land where trees are planted (Doss et al., 2012; Nabanoga et al., 2019). Moreover, agroforestry being a long-term enterprise means that allocating space for trees on the farm is long-term. Also, males' position as household heads perpetuates their leadership in decision-making since, to many, it comes with the decisive influence that overshadows other decisions within the household (Singh et al., 2016). In this study, decision-making power for most agroforestry decisions generally fell in the domain of the male decision-makers. The highest decision-making power of females was on selecting crop enterprises to integrate into a particular agroforestry plot – a decision linked to their social role of securing food for the household.

Societal and cultural norms in many parts of Africa usually assign females the role to ensure that household members receive adequate food (Kerr et al., 2016; Ragasa et al., 2019; Sraboni et al., 2014). The situation is not different in Uganda, particularly in the eastern highlands. Literature also shows that male decision-makers in dual-headed farming households are more interested in income-generating enterprises and often assign food crops' responsibility to their female counterparts (Shibata et al., 2020). In a patrilineal society of Uganda's eastern highlands, social and cultural practices that link males closer to their broader family groupings, such as patrilineal inheritance and patrilocal marriages, are meant to assign more powers to male decision-makers within a dual-headed household. Controlling income is how male decision-makers would consolidate their distinguished position of family headship. Therefore, males being the dominant decision-makers in the dual-headed household, are likely to have a selection bias toward income-generating technologies even when it is to the detriment of female aspirations in the household. This study found the two most critical factors in enhancing female decision-making power: education and males' involvement in off-farm income. Holding other factors constant, females' higher decision-making power in agroforestry was more likely in dual-headed households where females had higher levels of education. As discussed in chapter 3, more education for women improves self-confidence in articulating their ideas and tilting the overall household decisions in their favour. When their male counterparts became engaged with off-farm income-generating activities, females had more decision-making power regarding agroforestry. The limited time and attention offered to the farm by the males allow females to influence how agroforestry activities on the farm are implemented.

Regardless of the decision-maker in the dual-headed household, however, there is evidence that smallholder farmers are in continuous learning and experimentation with the technologies as they adapt them to their contexts (Hockett & Richardson, 2018). Importantly, smallholder farmers tend to modify the original configurations of the technologies introduced to them by scientists. In utilising the technology, smallholder farmers may also invent new practices to match the technologies appropriately to their farming systems. Such modifications and practices have been ignored in the general agroforestry adoption literature – with often the main focus of the studies being on why smallholder farmers adopt or do not adopt the recommended technologies. Yet there exist enormous lessons that can be learnt for future research and extension by examining how and why smallholder farmers modify and invent their practices in the course of using a recommended technology (Adesina & Chianu, 2002; Pretty, 1991). Therefore, Chapter 4 examined smallholder farmers' modifications and practices to make the agroforestry technologies (boundary planting, intercropping and woodlot) more useful to their contexts. Employing a case study strategy, it was found that regardless of the age and sex, cases either modified or used their own practices to enhance the technologies' useability to their context. These modifications and practices were categorised as seedling survival enhancing, benefit diversifying, space optimising, production cost minimising, and time shortening. As highlighted by the cases, most of the changes made to the recommended technologies and own practices had profound anticipated advantages to the household and underlying implications to farm productivity, which were not apparent. Related studies by Hockett and Richardson (2018) on smallholder farmers' modifications with new crop varieties in Malawi also categorised them based on their advantages. Cases across the three agroforestry technologies devised benefit diversifying modifications and practices. Increasing the benefits of a given technology through modifications enhance its perceived value (El-Haddadeh et al., 2019; Meinhold & Darr, 2020) and increases its choice probability among alternative options, as observed in chapter 2. Therefore, benefit diversification modifications and practices would increase the technology's relevance towards household needs, contexts and aspirations. For example, multiple tree species were a key benefit diversifying modification employed to tap into the different tree products and services. A study in Ghana on farmer-led innovations and household welfare found that households whose innovative activities were based on minor modifications of existing practices, tools and techniques reported more positive welfare effects than those based on major modifications (Tambo & Wünscher, 2017). Therefore, the impact of such modifications should not be under-estimated, given that they were reported to be more likely to contribute to smallholder farmers' livelihoods. Researchers need to build on them to facilitate the development and introduction of technologies that meet smallholder farmers' aspirations and are thus likely to be scaled out.

5.4 General conclusions

This study has demonstrated that the trajectory of agroforestry technology adaptation is conditioned by socio-technological and intra-household decision-making, which are embedded within the smallholder farmers' existing biophysical, socio-economic, and cultural contexts. From the socio-technological perspective, the perceived value of the technology, peer influence, and perception of own ability influenced smallholder farmers' choices of agroforestry technologies. On the other hand, Agroforestry is implemented through households as social units meaning that intra-household decisions affect the anticipated outcomes. In this study, male decision-makers dominated intra-household decision-making in the pre-production, production, and post-production phases of agroforestry technology utilisation. This has two implications. First, it means that the implementation and utilisation of agroforestry technologies may not meet females' needs and priorities. This makes females unable to benefit from agroforestry enterprises as they should. Second, it also means that agroforestry interventions that ignore males in their design and executions will continue to achieve limited success because they dominate decision-making power at the household level.

Nevertheless, females' highest decision-making power was reported in selecting crop enterprises to integrate into agroforestry plots – a decision linked to their social norms that dictate how, when, and about what females make decisions. These shared expectations (social norms) construct beliefs nested in females' minds and how they respond to males' masculinities expressed during the decision-making process. The study finds that females' influence in decision-making increases as their education and membership to farmers' organisations increase and their spouses engage in off-farm income-generating activities. This calls for affirmative action programmes, including adult literacy programmes for women designed to enhance their literacy and policies to reduce barriers to a girl child's primary and school education

Smallholder farming is complex and dynamic, and farmers are constantly required to respond to new livelihood challenges. The study findings demonstrate that farmers in the eastern highlands of Uganda are continuously modifying the recommended technologies to suit their context and coming up with their own practices to address livelihood challenges. Smallholder farmers' modifications and practices were categorised into seedling survival enhancing, benefit diversifying, space optimising, production cost-minimising, and time shortening. The drivers for modifications and practices, as explained in Chapter 4, seem to allude to smallholder farmers' desire to align the agroforestry technologies to their needs and objectives. A range of interlinked factors drove their modifications and practices: economic factors – such as the need to provide a quick and regular flow of income; environmental factors such as the need to shield their fields against strong winds; social factors such as avoiding conflicts with neighbours or addressing less labour availability; and cultural factors such as the need to have certain tree species for medicinal purposes. The knowledge that all cases possessed, as seen by the reasons underlying their modifications and practices, must be tapped into to generate socially acceptable technologies and enhance agroforestry's scaling-out. This study has unearthed agroforestry technology's ramifications (modifications and practices) into smallholder farmers' socio-economic and biophysical realities. It conforms to Rogers' (2010) iterations that technological packages do not circulate and spread as separate entities but are adjusted or re-invented as they are implemented locally. It further strengthens the argument that adoption studies that remain central to inform decision-making about the evaluation of newly introduced agroforestry technologies are too simplistic to capture the complex socio-technological reconfiguration in promoting agroforestry technologies.

5.5 Key recommendations

5.4.1 Policy recommendations

As highlighted in this study, smallholder farmers exhibited a lot of knowledge and experience in modifying agroforestry technologies because agroforestry is an integral part of the traditional farming system. Several of the modifications and practices highlighted through this study have the potential to be replicated by other smallholder farmers if they are proven to be working. However, the current agroforestry extension approaches use the transfer of technology model where smallholder farmers are perceived as learners and progressive adopters. For agroforestry technologies to be effective, they must be reshaped for smallholder farmers to adapt them to their farm situations. Therefore, there is a need to change from the conventional technology transfer model to a hybrid (knowledge exchange) model situated in the agricultural innovation system's thinking to allow smallholder farmers to contribute to agroforestry technology development. Future review of Uganda's agricultural extension policy should take note of smallholder farmers as potential sources of knowledge and include them on research advisory committees. This will help generate economically viable and socially acceptable technologies by smallholder farmers.

The relationship between the number of training sessions attended by the smallholder farmer and the choice of agroforestry technology is important to policy. This study suggests that the number of training sessions attended decreased the probability of choosing boundary planting technology, favouring better rewarding technologies (intercropping and woodlot). In the past, the efforts to integrate trees on the farm have provided planting materials rather than building farmers' capacity through messages tailored to a specific objective such as food and income security. An important part of government policy may be to increase the amount of resource allocation to capacity building to empower smallholder farmers to choose better rewarding technologies.

5.5.2 Recommendations to practice

Technology developers and promoters need to pay attention to intra-household decision-making dynamics, especially in dual-headed households. For example, women who mostly attend agroforestry training but have limited decision-making power may not easily implement what they learn. Households will be less likely to utilize agroforestry technologies, limiting the realised socio-economic benefits. Therefore, for agroforestry to achieve the desired outcomes, it's important to target both male and female decision-makers in a household so that their decisions are informed.

The modifications and practices that smallholder farmers were making seemed to make agroforestry systems even more complex—this further complicated smallholder farmers' ability to manage tree-crop interactions. For example, smallholder farmers used a mixture of tree species instead of single tree species in intercropping. Each tree species has its growth behaviour, making the cropping system more complex. Therefore, the smallholder farmers need to carry out timely management interventions (root pruning, canopy pruning and thinning). Yet, smallholder farmers tend to prioritise the management of crop enterprises other than trees. To leverage smallholder farmers' skills and knowledge in managing these complex farming systems, the use of demonstration trials should be enhanced, emphasising the deliberate and timely execution of the above management interventions.

It's probably fair to say that smallholder farmers in the eastern highlands of Uganda were very innovative in adapting technologies to their fields. It is clear from the study that farmers possess considerable knowledge that they use to confront their livelihood challenges. While it should not be assumed that indigenous knowledge alone will solve the many challenges smallholder farmers face, smallholder farmers should be encouraged as custodians of valuable farming knowledge that needs to be recognized and validated. The old ideas of using a top-down approach to transfer technologies to smallholder farmers may not work. Science may have a lot to offer resource-poor smallholder farmers. Still, the potential of local knowledge and farmer innovations will constitute its building blocks to generate technologies that are underpinned by the context to challenge 'business as usual'. Agroforestry could have a much more significant impact on the lives and livelihoods of smallholder farmers if more effort and thought went into understanding their context. This would call for extension workers to be more flexible while working with smallholder agroforestry farmers, knowing that they will not simply adopt technologies the way researchers have invented them.

5.5.3 Contribution to existing knowledge

Most of the studies on agroforestry technologies have dealt with adoption with a narrow focus on choices among alternative technologies, utilisation and modifications and practices in the socio-technological and intra-household decision-making contexts. For the first time in the context of the study area, this study has unearthed the hidden relationship between socio-technological factors and the adaptation of agroforestry technologies. The reasons behind smallholder farmers' choices and modifications of agroforestry technologies have been highlighted. Context-based inherent factors work in concert to drive tree-based investments for income, food security and environment among smallholder farmers have been discussed. It is not sufficient for agroforestry technologies to be assessed on ease of use and compatibility as it has been widely documented in the literature. This study that perceived value of agroforestry technologies in addressing the livelihood options of smallholder farmers is key to choice decisions.

The study contributed to the limited scope of knowledge in agroforestry technology adaptation and unearthed smallholder farmers' modifications and own practices in utilising agroforestry technologies. Suppose these modifications and practices could be distilled and validated. In that ase, they may be critical in enhancing the scaling-up of agroforestry and improving farm productivity and food security among smallholder farmers.

5.5.4 Implications for future research

This study has demonstrated that smallholder farmers undertake many modifications and practices to adapt agroforestry technologies to their farms. Some of these modifications and practices generate positive outcomes and should not be ignored. Therefore, researchers should work closely with smallholder farmers and other stakeholders in participatory research to find answers to specific problems, building on existing knowledge to validate smallholder farmers' modifications and practices to promote wide-scale uptake and integration into existing knowledge systems.

Whereas this study focused on intra-household decision-making, other factors external to the household can influence how agroforestry decisions are reached in the dual-headed household. For example, if either decision-maker has personal connections to a powerful politician, they may assume more decision-making power. Therefore, there is a need for future studies that combine both intra- and inter-household decision-making.

References

Acosta, M., van Wessel, M., van Bommel, S., Ampaire, E. L., Twyman, J., Jassogne, L., & Feindt, P. H. (2019). What does it Mean to Make a 'Joint' Decision? Unpacking Intra-household Decision Making in Agriculture: Implications for Policy and Practice. *The Journal of Development Studies*, *56*(6), 1210–1229. https://doi.org/10.1080/00220388.2019.1650169

Adesina, A. A., & Chianu, J. (2002). Determinants of farmers' adoption and adaptation of alley farming technology in Nigeria. *Agroforestry Systems*, *55*(2), 99–112. https://doi.org/10.1023/A:1020556132073

Alwang, J., Larochelle, C., & Barrera, V. (2017). Farm Decision Making and Gender: Results from a Randomised Experiment in Ecuador. *World Development*, *92*, 117–129. https://doi.org/10.1016/j.worlddev.2016.11.015

Anderson, J. R. (1993). The economics of new technology adaptation and adoption. *Review of Marketing and Agricultural Economics*, *61*(2), 301–309.

Brown, B., Nuberg, I., & Llewellyn, R. (2017). Negative evaluation of conservation agriculture: perspectives from African smallholder farmers. *International Journal of Agricultural Sustainability*, *15*(4), 467–481. https://doi.org/10.1080/14735903.2017.1336051

Burgess, P. J., Garcia de Jalon, S., & Graves, A. (Eds.) (2016). *Complexity and agroforestry: ways to embrace the challenge. EURAF2016 - Book of Abstracts*. Retrieved from https://www.repository.utl.pt/bitstream/10400.5/17584/1/EURAFIIIConf_Paul_Burgess_et_all_page_234_236.pdf

Ceballos, F., Kannan, S., & Kramer, B. (2020). Impacts of a national lockdown on smallholder farmers' income and food security: Empirical evidence from two states in India. *World Development*, *136*, 105069. https://doi.org/10.1016/j.worlddev.2020.105069

Cedamon, E., Nuberg, I., Pandit, B. H., & Shrestha, K. K. (2018). Adaptation factors and futures of agroforestry systems in Nepal. *Agroforestry Systems*, *92*(5), 1437–1453. https://doi.org/10.1007/s10457-017-0090-9

Dagar, J. C., & Tewari, V. P. (2017). *Agroforestry: Anecdotal to modern science / edited by Jagdish Chander Dagar, Vindhya Prasad Tewari*. Singapore: Springer Singapore: Imprint: Springer. https://doi.org/10.1007/978-981-10-7650-3

Doss, C., Truong, M., Nabanoga, G., & Namaalwa, J. (2012). Women, Marriage and Asset Inheritance in Uganda. *Development Policy Review*, *30*(5), 597–616. https://doi.org/10.1111/j.1467-7679.2012.00590.x

El-Haddadeh, R., Weerakkody, V., Osmani, M., Thakker, D., & Kapoor, K. K. (2019). Examining citizens' perceived value of internet of things technologies in facilitating public sector services engagement. *Government Information Quarterly*, *36*(2), 310–320. https://doi.org/10.1016/j.giq.2018.09.009

Hockett, M., & Richardson, R. B. (2018). Examining the drivers of agricultural experimentation among smallholder farmers in Malawi. *Experimental Agriculture*, *54*(1), 45–65.

Kahane, R., Hodgkin, T., Jaenicke, H., Hoogendoorn, C., Hermann, M., Keatinge, J. D. H., . . . Looney, N. (2013). Agrobiodiversity for food security, health and income. *Agronomy for Sustainable Development*, *33*(4), 671–693. https://doi.org/10.1007/s13593-013-0147-8

Kerr, R. B., Chilanga, E., Nyantakyi-Frimpong, H., Luginaah, I., & Lupafya, E. (2016). Integrated agriculture programs to address malnutrition in northern Malawi. *BMC Public Health*, *16*(1), 1197. https://doi.org/10.1186/s12889-016-3840-0

Kmoch, L., Pagella, T., Palm, M., & Sinclair, F. (2018). Using Local Agroecological Knowledge in Climate Change Adaptation: A Study of Tree-Based Options in Northern Morocco. *Sustainability*, *10*(10), 3719. https://doi.org/10.3390/su10103719

Li, M., Wang, J., Zhao, P., Chen, K., & Wu, L. (2020). Factors affecting the willingness of agricultural green production from the perspective of farmers' perceptions. *The Science of the Total Environment*, *738*, 140289. https://doi.org/10.1016/j.scitotenv.2020.140289

Meinhold, K., & Darr, D. (2020). Using a multi-stakeholder approach to increase value for traditional agroforestry systems: the case of baobab (Adansonia digitata L.) in Kilifi, Kenya. *Agroforestry Systems.* Advance online publication. https://doi.org/10.1007/s10457-020-00562-x

Nabanoga, G. N., Namaalwa, J. J., & Bomuhangi, A. (2019). Impacts of Climate Change on Small Holder Households in Mt. Elgon Region of Uganda: Does Gender Matter? In Y. Bamutaze, S. Kyamanywa, B. R. Singh, G. N. Nabanoga K., & R. Lal (Eds.), *Climate change management, 1610-2010. Agriculture and ecosystem resilience in Sub Saharan Africa: Livelihood pathways under changing climate/editors, Yazidi Bamutaze, Samuel Kyamanywa, Bal Ram Singh, Goretti Nabanoga and Rattan Lal* (pp. 673–690). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-12974-3_30

Ndoli, A., Baudron, F., Schut, A. G., Mukuralinda, A., & Giller, K. E. [Ken E.] (2017). Disentangling the positive and negative effects of trees on maize performance in smallholdings of Northern Rwanda. *Field Crops Research*, *213*, 1–11. https://doi.org/10.1016/j.fcr.2017.07.020

Pretty, J. N. (1991). Farmers' extension practice and technology adaptation: Agricultural revolution in 17–19th century Britain. *Agriculture and Human Values*, *8*(1-2), 132–148. https://doi.org/10.1007/BF01579666

Ragasa, C., Aberman, N.-L., & Alvarez Mingote, C. (2019). Does providing agricultural and nutrition information to both men and women improve household food security? Evidence from Malawi. *Global Food Security*, *20*, 45–59. https://doi.org/10.1016/j.gfs.2018.12.007

Rogers, E. M. (2010). *Diffusion of innovations* (4th Edition). New York: Simon and Schuster.

Ronner, E., Descheemaeker, K., Almekinders, C. J. M., Ebanyat, P
(2018). Farmers' use and adaptation of improved climbing bean
highlands of Uganda. *Agriculture, Ecosystems & Environment*,
https://doi.org/10.1016/j.agee.2017.09.004

Shibata, R., Cardey, S., & Dorward, P. (2020). Gendered Intra-Hou
Dynamics in Agricultural Innovation Processes: Assets, Norms
Journal of International Development, *32*(7), 1101–1125. https:

Singh, C., Dorward, P., & Osbahr, H. (2016). Developing a holistic
farmer decision-making: Implications for adaptation policy and
countries. *Land Use Policy*, *59*, 329–343. https://doi.org/10.101

Sraboni, E., Malapit, H. J., Quisumbing, A. R., & Ahmed, A. U. (2
Empowerment in Agriculture: What Role for Food Security in B
Development, *61*, 11–52. https://doi.org/10.1016/j.worlddev.20

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A.,
Food system resilience: Defining the concept. *Global Food Sec*
https://doi.org/10.1016/j.gfs.2015.08.001

Van Noordwijk, M., Lawson, G., Hairiah, K., & Wilson, J. (2015).
crops: competition and/or complementarity (2nd Edition). *Tree-*
Agroforestry in a Changing Climate. Wallingford, UK: CABI. F
http://nora.nerc.ac.uk/id/eprint/511997/1/N511997BC.pdf

Wang, H.Y., & Wang, S.H. (2010). Predicting mobile hotel reserva
perceived value standpoint. *International Journal of Hospitality*
608. https://doi.org/10.1016/j.ijhm.2009.11.001

LIST OF APPENDICES

Appendix 1: Guide for key informant on smallholder farmers adaptation of agroforestry technologies in the eastern highlands of Uganda

Process

Before undertaking any interview, I introduced myself by name and institution. I explained the purpose of the interview and re-assured the respondent(s) of the confidentiality of the information provided. I sought consent from the respondents for their willingness to participate, allow us to take notes and photos, and use an audio recorder to capture our conversations.

1 General information

1.1 Date and location of the interview

1.2 Name of the respondent

1.3 Name of the organization/institution/programme

1.4 Role in the promotion of agroforestry in the study area

2 Key informant checklists

2.1 What is your role in the promotion of agroforestry in this area?

2.2 Why do you think this role is essential?

2.3 How do you execute your role?

2.4 What is the spread of your work in the region?

2.5 What is the scope of your work?

2.6 Mention any other organisations/institutions doing related to agroforestry work in the area

2.7 What is your opinion on the willingness of the farmers to implement agroforestry?

2.8 How do you rate the increase in the uptake of the agroforestry technologies?

2.9 In your view, which areas (sub-counties) would you call model areas for the utilization of agroforestry in the area? Why?

2.10 Which agroforestry technologies do you promote in the area?

2.11 Of the technologies, which one do you consider as the most popular?

2.12 What makes the above technologies popular among smallholder farmers?

2.13 Do you think smallholder farmers utilise the agroforestry technologies as recommended by the experts?

2.14 If not, what do they adjust in the experts' recommendations?

2.15 In your view, what is the proportion of farmers who are using the technology the way they are recommended vis-vis those modifying?

2.16 Why do you think smallholder farmers make such adjustments?

2.17 What do you think are the possible advantages and disadvantages of smallholder farmers modifications?

Appendix 2: Guide for FGDs on smallholder farmers choices of agroforestry technologies in the eastern highlands of Uganda

Process

Before undertaking any FDG, I introduced myself by name and institution as well as my research assistant. I explained the purpose of the interview and re-assured the participants of the confidentiality of the information provided. I sought consent from the participants for their willingness to participate, allow us to take notes and photos, and use an audio recorder to capture our conversations. During the FGDs, I was keen to observe and capture non-verbal expressions as these would show a level of satisfaction or necessitate further probing regarding an issue.

1. General information

1.1 Date and location of the interview

1.2 Name of the category of the focus group

1.3 Number of participants by sex

2 FGD interview checklist

2.1 Which organisations are promoting agroforestry in your area?

2.2 List the technologies that are being promoted

2.3 Which are the most commonly implemented technologies in your community? (please rank)

2.4 What are the main characteristics of these technologies as implemented by the smallholder farmers?

2.5 Why do you think these are the most common?

2.6 What tree species do you commonly integrate into each technology and why?

2.7 Who are the people at home involved in making decisions on utilising the technologies at home?

2.8 What are the critical decisions made at the household level during the implementation of agroforestry?

2.9 Which fears do you have as regards implementing the technology as recommended?

2.10 Which recommended guidelines do smallholder farmers modify during the utilization of the agroforestry technologies

2.11 Why are they changing the mentioned recommendations?

2.12 What do you observe on your farms as a result of the modifications?

Appendix 3: Household survey questionnaire about the influence of socio-technological factors on smallholder farmers' choices of agroforestry technologies in the eastern highlands of Uganda

Seeking the respondent consent

Greet and introduce yourself to the respondent. Tell him/her that you have come to conduct research for academic purposes to understand the rationale for smallholder farmers' choices of agroforestry technologies. Emphasise to the respondent that the information provided will be confidential. Tell the respondent that the interview will take a maximum of two hours. Ask the respondent if he/she is willing to be part of the study. If s/he accepts to be part of the study, thank him/her and proceed with the interview.

Interview identification

Name of the Enumerator		Questionnaire number		
Household ID (D.S.001)		Date of interview		
Name of the HH head		Tel. No.		
Village		Parish		
Sub-county		District		
GPS coordinates	N	E	Altitude (m)	

SECTION 1: Details of demographic and socio-economic characteristics of the household

(*Household is a group of people -including resident workers and servants, who constantly live, cook and eat together*)

1.1 What is the gender of the respondent (preferably household head or spouse)? *(Please circle)*

1 = Male 2 = Female

1.2 What is the relationship of the respondent with the household head? *(Please circle)*

1 = Household head	6 = Daughter-in-law
2 = Spouse	7 = Grand son
3 = Son	8 = Grand daughter
4 = Daughter	9 = Labourer/Caretaker
5 = Son in-law	8 = Other relative Specify.........................

1.3 Which year was the respondent born?....................

1.4 What is the marital status of the respondent? *(Please circle)*

1 = Single	4 = Divorced
2 = Married	5 = Separated

3 = Widowed

1.5 Has the respondent ever attended school? *(Please circle)*

1 = Yes 2 = No

1.6 If yes, what is the highest education level attained by the respondent? *(Please circle the code and indicate the exact level/class)*

1 = Primary ....

2 = Secondary ....

3 = High school.....................

4 = Certificate after S.4

5 = Certificate after high school

6 = Diploma after S.4

7 = Diploma after high school

8 = Degree after diploma

9 = Degree after high school

1.7 Has the respondent attended any agricultural-related training in the past 12 months? *(Please circle)*

1 = Yes 2 = No

1.8 If yes, please specify what the training was about *(you can tick more than one option)*

1 = Livestock production
2 = Crop production
3 = Tree growing
4 = Soil & Water Conservation
5 = Climate change
6 = Value addition
7 = Marketing
8 = Farm planning
9 = Record keeping

1.9 What is the tenure status of the land accessed by the household in the last 12 months? *(Multiple – Please circle the code and specify the size)*

CODE *(Tick, multiple)*	**Variable**	**Total (acres)**
1	Land inherited by the household	
2	Land purchased by the household	
3	Land rented by the household	
4	Land borrowed by the household	
5	Total land accessed	

1.10 How many people in the following categories stay in your household?

Category	Number
1 = School going (6 – 17 years)	
2 = Out-of-school (Dropouts) (6 – 17 years)	
3 = Adults (18 – 60 years)	
4 = Infants (below 6 years)	
5 = Elderly (over 60 years)	
Total members of the household	

1.11 How many people are involved in farm activities in your household?.................................

SECTION 2: Description of the farming system of the household

2.1 What is the primary occupation of the household in the previous 12 months? *(Please circle one alternative)*

1 = Annual crop production
2 = Perennial Crop production
3 = Livestock production
4 = Salaried employment
5 = Self-employed off-farm
6 = Casual labourer on-farm

2.1.1 Please specify the enterprise ....

2.2 Concerning the past 12 months, list up to 3 most important agricultural enterprises (Crop, Livestock and Tree) of the household in the table below and rank their importance to food and income security

Enterprise category	**Rank for food security** *(1 = Most important, 3 = Least important)*	**Rank for income security** *(1 = Most important, 3 = Least important)*
Crop enterprise		
Livestock enterprises		
Tree enterprises (please circle and specify tree species in any selected three option)		
1 = Fruits		
3 = Fodder		
4 = Firewood		
5 = Timber/poles		
6 = Herbal medicine		

2.3 When was the first time the respondent independently planted trees (agroforestry) on their farm? *(Fill in the year)*

....

2.4 Has the respondent ever received a training on tree growing? *(circle)*

1 = Yes 2 = No

2.5 What was the respondent's source of training about tree growing? *(Circle multiple and specify where possible)*

1 = Research Institute ....
2 = NGO ....
3 = Lead farmer
4 = NAADS/OWC
5 = Sub-county Extension Officer
6 = District Extension Officer
7 = CBO..................................

2.6 What are the adapted agroforestry practices implemented by the household on their farm? *(Please circle, provide the acreage and number of trees and priority in each technology)*

CODE	Agroforestry technology	Size of land (acres) under practice	Number of trees incorporated	Priority of the technology
1	Boundary planting			
2	Intercropping			
3	Woodlot			

2.7 Please provide details of the agroforestry practice implemented on the farm

Agroforestry practice	Crop/Animal enterprises practised on the plot before	Crop or animal enterprises currently on the plot	Tree species planted (multiple)	Year of planting	The spacing used *(in metres)*		Number of trees	Source of seedlings
					Between lines	Between plants		
Boundary			1 = Maesopsis (Musizi)					
			2 = Cordia (Shichikhili)					
			3 = Albizzia (Shilukhu)					
			4 = Melia (Lira)					
			5 = Grevillea (Mitikawa)					
			6 = Neolamarkhia (Proscovia)					
			7 = Eucalyptus (Chimiti)					
			8 = Calliandra (Kaliyandra)					
			9 = Agrocarpus					
			10 = Mangifera (Kumuyembe)					
			11 = Persea (Focedo)					
			12 = Artocarpus (Ffene)					
			13 = Pine					
			14 = Markhamia					

Agroforestry practice	Crop/Animal enterprises practised on the plot before	Crop or animal enterprises currently on the plot	Tree species planted (multiple)	Year of planting	The spacing used *(in metres)*		Number of trees	Source of seedlings
					Between lines	Between plants		
Intercropping			1 = Maesopsis (Musizi)					
			2 = Cordia (Shichikhili)					
			3 = Albizzia (Shilukhu)					
			4 = Melia (Lira)					
			5 = Grevillea (Mitikawa)					
			6 = Neolamarkhia (Proscovia)					
			7 = Eucalyptus (Chimiti)					
			8 = Calliandra (Kaliyandra)					
			9 = Agrocarpus					
			10 = Mangifera (Kumuyembe)					
			11 = Persea (Focedo)					
			12 = Artocarpus (Ffene)					
			13 = Pine					
			14 = Markhamia					

Agroforestry practice	Crop/animal enterprises practised on the plot before	Crop/animal enterprises currently on the plot	Tree species planted (Multiple)	Year of planting	The spacing used *(metres)* Between plants	Number of trees	Source of seedlings
woodlot			1 = Maesopsis (Musizi)				
			2 = Cordia (Shichikhili)				
			3 = Albizzia (Shilukhu)				
			4 = Melia (Lira)				
			5 = Grevillea (Mitikawa)				
			6 = Neolamarkhia (Proscovia)				
			7 = Eucalyptus (Chimiti)				
			8 = Calliandra (Kaliyandra)				
			9 = Agrocarpus				
			10 = Mangifera (Kumuyembe)				
			11 = Persea (Focedo)				
			12 = Artocarpus (Ffene)				
			13 = Pine				
			14 = Markhamia				

2.8 Which agroforestry practice uses most of the household land?

1 = Boundary planting 2 = Intercropping 3 = Woodlot

2.9 Please give the main reason for allocating it more land

....

SECTION 3: Factors influencing the choice of the primary agroforestry practice *(please refer to Q2.6 for the predominant agroforestry practice on the farm)*

3.1 Read through the following statements for each respondent to decide how much s/he agrees or disagrees with each. Circle the number that best indicates how the respondent feels about each statement. *Scale: **1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.***

Statement	Score (Please circle)
Perceived value	
Household needs for ***herbal medicine*** influenced the respondent to use the agroforestry technology	1 2 3 4 5
The agroforestry technology would ***increase firewood availability*** in the household	1 2 3 4 5
I was convinced that the agroforestry technology would help me to increase household **income**	1 2 3 4 5
The agroforestry technology would help me ***enhance food availability*** (fruits) to the household	1 2 3 4 5
The agroforestry technology would help me ***enhance fodder availability*** to the household	1 2 3 4 5
I wanted to provide ***shade to crops***	1 2 3 4 5
I desired ***to increase soil fertility*** on the farm	1 2 3 4 5
The use of the agroforestry technology would help me to make use of ***degraded/unproductive sites*** on the farm	1 2 3 4 5
I wanted to provide a supply of ***building materials*** for domestic structures	1 2 3 4 5
Perceived ease of use	

The use of the agroforestry technology ***required technical knowledge***	1	2	3	4	5
There was a need for ***prior experience*** to use the agroforestry technology	1	2	3	4	5
The agroforestry technology required ***much labour*** to be implemented	1	2	3	4	5
Compatibility with other components on the farm					
Implementing the agroforestry technology necessitated me to ***rearrange the existing enterprises***	1	2	3	4	5
The technology was ***suiting my household farming objectives***	1	2	3	4	5
The tree species used in the system have a ***direct effect on existing crops***	1	2	3	4	5
The technology is ***appropriate to the landscape location of the farm***	1	2	3	4	5
Subjective norms					
I was influenced by the ***researchers*** (e.g. NARO, MAK, ICRAF) to use the agroforestry technology	1	2	3	4	5
I was influenced by ***the extension workers (local government)*** to use the agroforestry technology	1	2	3	4	5
The presence of ***other farmers*** who were already using the agroforestry technology influenced me to use it	1	2	3	4	5
I felt motivated to use the agroforestry technology because ***NGOs were promoting*** it in the area	1	2	3	4	5
CBOs operating in the area influenced me to use the agroforestry technology	1	2	3	4	5
perceived behavioural control (Available resources)					
Technical information received was sufficient for me to use the agroforestry technology	1	2	3	4	5
I had ***access to tree seedlings*** needed to implement the agroforestry technology	1	2	3	4	5
My ***previous experience in tree growing*** was vital in influencing me to use the agroforestry technology	1	2	3	4	5
Given the ***size of land accessed***, this was the most appropriate agroforestry technology	1	2	3	4	5

The ***availability of labour*** needed to implement the agroforestry technology was a key consideration	1	2	3	4	5
The choice of agroforestry technology was based on the ***self-confidence and determination*** I had at the time	1	2	3	4	5

Appendix 4: A household survey to examine the influence of intra-household decision-making on the utilisation of agroforestry technologies

Seeking the respondent consent

Greet and introduce yourself to the respondent. Tell him/her that you have come to conduct research for academic purpose understanding the intra-household decision-making in agroforestry. Emphasise to the respondent that the information provided will be confidential. Tell the respondent that the interview will take a maximum of two hours. Ask the respondent if he/she is willing to be part of the study. If s/he accepts to be part of the study, thank him/her and proceed with the interview.

Instructions

i. *Enumerators should work in pairs (male and female)*
ii. *The male and female enumerators should interview male and female decision-makers respectively where separate responses are required*
iii. *The modalities of the interview should be explained clearly, and consent should be sought from the household head to interview their spouse separately*
iv. *Questions that require one response for the household should be responded to by both through consensus. These should be asked first before separation*
v. *Circle the appropriate codes where applicable*

Interview identification

Name of the Enumerator			Questionnaire number		
Household ID (D.S.001)		Date of interview			
Name of the HH head			Tel. No.		
Village		Parish			
Sub-county		District			
GPS coordinates	N		E	Altitude (m)	

SECTION 1: Household wealth status

1.1 What is the size of land (acres) owned (both purchased and inherited) by the household?
(Refer to question 1.9) ....

1.2 Please provide information on livestock keeping in the household

CODE *(Please tick)*	Type of livestock	Number
1	Cattle	
2	Goat	
3	Pig	
4	Donkey	
5	Chicken	
6	Turkey	
7	Duck	
8	Beekeeping	

1.3 Provide information on the major perennial cash crop on the farm

CODE *(Please tick)*	Type of crop	Area (acres)
1	Coffee	
2	Banana	
3	Trees (Wood, Timber, Firewood, Poles)	
4	Passion fruits	
5	Fruit trees	

1.4 How many paid permanent farmworkers do you have? ....

1.5 How many casual workers do you hire during the peak season? ....

1.6 Which transport mean is owned by the household? *(please circle)*

1 = Car 2 = Motorcycle 3 = Bicycle 4 = Donkey 5 = Cart 6 = None

SECTION 2: Details of demographic and socio-economic characteristics of the respondent (answered separately)

2.1 For each of the explanatory variables below indicate for both male and female decision-maker

Variable	Decision-maker	
	Male	**Female**
When was the respondent born?		
Has the respondent ever attended school?	1 = Yes 2 = No	1 = Yes 2 = No
If yes, please specify the highest class attained		
How many hours does the respondent spend on farming activities daily?		
Does the respondent hold any community responsibility?	1 = Yes 2 = No	1 = Yes 2 = No
If yes, please specify *(In case of many, the respondent should specify the most engaging)*		
Does the respondent receive any off-farm income?	1 = Yes 2 = No	1 = Yes 2 = No
If yes, please specify the primary source		
Is the respondent a member to any farmer organization?	1 = Yes 2 = No	1 = Yes 2 = No
Has the respondent ever attended any training on tree farming (agroforestry)?	1 = Yes 2 = No	1 = Yes 2 = No

2.2 How many years have you spent together as husband and wife?

……………………………………..

2.3 How do you categorise the farming household?

1. Subsistence 2. Semi-subsistence 3. Commercial

SECTION 3: Roles and responsibilities of spouses during the implementation of agroforestry activities

3.1 For each of the explanatory variables below indicate for both male and female decision-maker

Variable	Male response			Female response		
	Self	Female	joint	Self	Male	Joint
Attending agroforestry training sessions						
Preparing land for tree planting						
Planting of tree seedlings						
Integrating crop enterprises in agroforestry plot						
Weeding						
Pruning						
Thinning						
Protecting trees against damage						
Harvesting of tree products						
Marketing of tree products						

4.2 Please ask the respondent to rate the extent to which tree growing (agroforestry) has contributed to the following in their household *(Please circle the appropriate rate **where 1 = Very Poor, 2 = Poor, 3 = Neutral, 4 = Good, 5 = Very Good)***

Variable	**Male decision-maker**					**Female**				
Improved **crop yields** on the farm	1	2	3	4	5	1	2	3	4	5
Improved **food security** in the household	1	2	3	4	5	1	2	3	4	5
Improved **fuelwood** situation in the household	1	2	3	4	5	1	2	3	4	5
Improved household **income** through the sale of tree products	1	2	3	4	5	1	2	3	4	5

4.3 Ask each of the spouses to rank their preferred three tree species among those existing on the farm

Male decision-maker			**Female decision-maker**		
Species	Rank	Reason for the rank	Species	Rank	Reason for the rank
1.			1.		
2.			2.		
3.			3.		

Thank you/Wanyala

Appendix 5: In-depth interview guide (case study)

Process

After greeting the case (selected smallholder farmer), I introduced yourself and explained my research objective. I asked the case to be flexible and cooperative with me because I would keep engaging him/her even after the interview if I needed more information. I emphasized that the information provided was going to be treated as confidential. I also sought permission to use the audio recorder and take pictures where applicable to capture phenomena on his/her farm. All this was done before proceeding with the interview.

1 Basic information

1.1 Date of the interview

1.2 Name of the case

1.3 Location (village, sub-county, district)

1.4 Age

1.5 Type of agroforestry technology

2 Checklist to guide the conversation

2.1 Did the case understand the original design of the technology as promoted by the experts?

2.2 What were the fears in implementing the technology as recommended by the experts?

2.3 Which aspects of the technology (recommended practices) did the farmer adjust in the technology to make it more relevant to his/her situation?

2.4 What are the different adjustments/modifications?

2.5 What own generated practices does the case undertake to make the technology more useful to his household?

2.6 What are the current/anticipated benefits from the modifications and practices as applied by the case?

2.7 What challenges does the case observe/foresee due to his/her modifications and practices?