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# Agroforestry Adoption in Ethiopia: Innovation Systems and Farm Level Analysis

**Dissertation**
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**Declaration of conformity**

I confirm that this copy conforms to the original dissertation on the topic:

**"Agroforestry Adoption in Ethiopia: Innovation Systems and Farm Level Analysis"**

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**Dagninet Amare Aysheshim**

**PREFACE**

This study was conducted from April 2018 to October 2022. Mixed research methods are applied, and econometric models served as primary analytical tools. The results of this research presumably contribute to both research and policy in regards to adoption by showcasing robust research approach and suggesting actionable policy recommendations. This dissertation comprises introduction, results (3 published and 2 submitted manuscripts) and synthesis and conclusion sections.

1. Dagninet Amare, Dietrich Darr (2020) Agroforestry adoption as a system concept: A review. *Forest Policy and Economics, 120 (2020) 102299.*
2. Dagninet Amare, Dietrich Darr (2022) Farmers intentions towards sustained agroforestry adoption: An application of the theory of planned behavior. *Journal of Sustainable Forestry*, *https://doi.org/10.1080/10549811.2022.2123358*.
3. Dagninet Amare, Dietrich Darr (2023) Can a sequential analysis provide a more robust understanding of farmers' adoption decisions? An example from an agroforestry adoption study from Ethiopia. *Forest Policy and Economics, 153(2023)102997.*
4. Dagninet Amare, Dietrich Darr (forthcoming) Adoption under the influence of innovation attributes: the case of agroforestry innovations from Ethiopia. *Under review in World Development.*
5. Dagninet Amare, Dietrich Darr (forthcoming) Influence of system level factors on adoption of agroforestry innovations. *Under review in Environmental Development*.

Additionally, the student collaboratively published 4 more articles , separate from the PhD project, during this period (https://doi.org/10.1007/s11842-018-9405-6 , https://doi.org/10.1002/ldr.3689, https://doi.org/10.1007/s10457-018-0285-8 , and https://doi.org/10.3389/fenvs.2022.965408 ).

**OUTLOOK**

This PhD project largely achieved the objectives set at first. To further accomplish transparency, development and academic intentions and reach out to actors, we aim to share the entire generated information by publishing excluded parts (i.e., profitability and holistic analysis), developing policy briefs, and test the framework on food and traditional agroforestry innovations adoption to more clearly discern its capability for revealing practically critical factors to enhance the contribution of agroforestry for economic and environmental benefits.

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**SUMMARY**

Agroforestry (AF) or agroforestry innovation (AFI) production has long been and continues to be a component of the mixed farming system of Ethiopian and smallholder farmers worldwide. Interventions continue introducing new or improved management practices, species, and techniques to raise AFI's livelihood and natural resource management contributions. Despite considerable efforts, the adoption of these AFI continues to be limited, as proved by several adoption studies and development efforts. Formal and informal studies were conducted for decades to understand the problems for the low adoption of various AFI. Nevertheless, these studies generated redundant and marginally growing important information as it has weakly altered the course of development approaches and policy regulations.

Learning from previous studies, researchers have been requesting more robust studies that help address existing knowledge gaps on adopting AFI. To respond to these calls, this PhD project examined the factors affecting the adoption of AFI by smallholders and Ethiopian farmers as a case study. The project builds upon previous studies to explore the diverse perspectives that influence the adoption of AFI.

Literature assessment of recent studies indicated that several factors belonging to farmers and institutions influence the adoption of AFI. Simultaneously, we discovered that some issues were explored frequently (e.g., socioeconomic factors), whereas others (e.g., psychological factors) were largely ignored. Besides, researchers have followed the static assumption (i.e., adopt or non-adopt) and failed to learn the adoption process beyond a one-time decision. Additionally, the studies focused on discrete factors and activities and failed to comprehend the diverse perspectives and factors and their combined effect on eventual AFI adoption. Ultimately, learning from the larger adoption science and previous studies, we developed a comprehensive framework, 'AFI adoption framework' (chapter 4.1), that supports the meaningful assessment of adoption practices and comprehensively discovers factors influencing AFI adoption. The framework encompassed three compartmentalized and yet interlinked components that influence AFI adoption under smallholder contexts. The framework commended both distinct studies for exhaustive elaboration and simultaneously suggested holistic examination. Besides, it recommended minor and major modifications to the research approaches, such as proper treatment of variables in econometric models, incorporation of variables related to the psychological status, and employment of robust tools such as the real-options approach for profitability analysis.

Based on this framework, we designed a project and conducted fieldwork in the Amhara region of Ethiopia, a typical smallholder context. We explored the household contexts (i.e., farm level and psychological), system level features, and innovation characteristics influencing smallholders' AFI adoption decisions. It employed mixed conventional and advanced analytical tools comprising content analysis, econometric models, principal component analysis, and financial discounting methods. Advanced methods comprehend process analysis and adoption dynamism.

The results from discrete analysis indicated that socioeconomic factors, psychological constructs, system level features, and innovation attributes influence AFI adoption. Regarding innovation characteristics, the different attributes are foundations for undertaking AFI adoption decisions of smallholder farmers. Beyond adopt-non-adopt concepts, we found farmers continuously undertake follow-up adoptions of varying extents such as reduced, maintained, and increased.

Based on our query and comparable to existing frameworks, the newly developed *'AFI adoption framework'* is more reasonable to meaningfully investigate factors influencing AFI (and agricultural innovations) adoption under smallholder contexts. However, there is a need for precaution while employing the framework to more clearly discern the adoption process and reflect the integration among the factors and activities involved from the development to the adoption of AFI. This dissertation excluded empirical analysis of profitability and holistic assessment due to the voluminous nature of the dissertation.

**Keywords:** agroforestry innovations, adoption, smallholders, Ethiopia

**ZUSAMMENFASSUNG**

Die Produktion von Agroforstwirtschaft (AF) oder Agroforstwirtschaft (AFI) war und ist seit langem Bestandteil des gemischten landwirtschaftlichen Systems von Äthiopien und Kleinbauern weltweit. Interventionen führen weiterhin neue oder verbesserte Bewirtschaftungspraktiken, Arten und Techniken ein, um die Beiträge von AFI zum Lebensunterhalt und zur Bewirtschaftung natürlicher Ressourcen zu erhöhen. Trotz erheblicher Bemühungen ist die Einführung dieser AFI weiterhin begrenzt, wie mehrere Adoptionsstudien und Entwicklungsbemühungen belegen. Formelle und informelle Studien wurden jahrzehntelang durchgeführt, um die Probleme für die geringe Akzeptanz verschiedener AFI zu verstehen. Dennoch generierten diese Studien redundante und geringfügig wachsende wichtige Informationen, da sie den Kurs von Entwicklungsansätzen und politischen Regulierungen schwach verändert haben.

Aus früheren Studien lernend, haben Forscher robustere Studien angefordert, die dazu beitragen, bestehende Wissenslücken bei der Einführung von AFI zu schließen. Um auf diese Aufrufe zu reagieren, untersuchte dieses PhD-Projekt die Faktoren, die die Einführung von AFI durch Kleinbauern und äthiopische Bauern beeinflussen, als Fallstudie. Das Projekt baut auf früheren Studien auf, um die vielfältigen Perspektiven zu untersuchen, die die Einführung von AFI beeinflussen.

Die Literaturbewertung neuerer Studien zeigte, dass mehrere Faktoren, die Landwirten und Institutionen angehören, die Einführung von AFI beeinflussen. Gleichzeitig stellten wir fest, dass einige Themen häufig untersucht wurden (z. B. sozioökonomische Faktoren), während andere (z. B. psychologische Faktoren) weitgehend ignoriert wurden. Außerdem sind die Forscher der statischen Annahme gefolgt (d. h. adoptieren oder nicht adoptieren) und haben es versäumt, den Adoptionsprozess über eine einmalige Entscheidung hinaus zu lernen. Darüber hinaus konzentrierten sich die Studien auf diskrete Faktoren und Aktivitäten und konnten die unterschiedlichen Perspektiven und Faktoren und ihre kombinierte Wirkung auf die eventuelle Einführung von AFI nicht verstehen. Letztendlich haben wir aus der größeren Adoptionswissenschaft und früheren Studien gelernt und einen umfassenden Rahmen entwickelt, den „AFI-Adoptionsrahmen“ (Kapitel 4.1), der die aussagekräftige Bewertung von Adoptionspraktiken unterstützt und Faktoren, die die AFI-Adoption beeinflussen, umfassend

aufdeckt. Der Rahmen umfasste drei unterteilte und dennoch miteinander verbundene Komponenten, die die Einführung von AFI im Kontext von Kleinbauern beeinflussen. Der Rahmen empfahl beide getrennten Studien für eine erschöpfende Ausarbeitung und schlug gleichzeitig eine ganzheitliche Untersuchung vor. Außerdem empfahl es kleinere und größere Modifikationen der Forschungsansätze, wie z. B. die angemessene Behandlung von Variablen in ökonometrischen Modellen, die Einbeziehung von Variablen im Zusammenhang mit dem psychologischen Status und die Verwendung robuster Werkzeuge wie des Real-Options-Ansatzes für die Rentabilitätsanalyse. Basierend auf diesem Rahmen haben wir ein Projekt entworfen und Feldforschung in der Region Amhara in Äthiopien durchgeführt, einem typischen kleinbäuerlichen Kontext. Wir untersuchten die Haushaltskontexte (d. h. auf Betriebsebene und psychologisch), Merkmale auf Systemebene und Innovationsmerkmale, die die AFI-Adoptionsentscheidungen von Kleinbauern beeinflussen. Es verwendete gemischte konventionelle und fortschrittliche Analysewerkzeuge, darunter Inhaltsanalyse, ökonometrische Modelle, Hauptkomponentenanalyse und finanzielle Diskontierungsmethoden. Fortgeschrittene Methoden umfassen Prozessanalyse und Adoptionsdynamik.

Die Ergebnisse der diskreten Analyse zeigten, dass sozioökonomische Faktoren, psychologische Konstrukte, Merkmale auf Systemebene und Innovationsattribute die Akzeptanz von AFI beeinflussen. In Bezug auf Innovationsmerkmale sind die verschiedenen Attribute Grundlage für die Durchführung von AFI-Adoptionsentscheidungen von Kleinbauern. Abgesehen von Adoptions-Nicht-Adoptionskonzepten haben wir festgestellt, dass Landwirte kontinuierlich Folgeadoptionen in unterschiedlichem Ausmaß durchführen, z. B. reduziert, beibehalten und erhöht. Basierend auf unserer Anfrage und vergleichbar mit bestehenden Frameworks, ist das neu entwickelte „AFI Adoption Framework“ sinnvoller, um Faktoren, die die Adoption von AFI (und landwirtschaftlichen Innovationen) im Kontext von Kleinbauern beeinflussen, sinnvoll zu untersuchen. Bei der Anwendung des Frameworks ist jedoch Vorsicht geboten, um den Einführungsprozess klarer zu erkennen und die Integration zwischen den beteiligten Faktoren und Aktivitäten von der Entwicklung bis zur Einführung von AFI widerzuspiegeln. Diese Dissertation verzichtete aufgrund des Umfangs der Dissertation auf eine empirische Wirtschaftlichkeitsanalyse und eine ganzheitliche Bewertung.

Schlüsselwörter: Innovationen in der Agroforstwirtschaft, Adoption, Kleinbauern, Äthiopien

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## ACRONYMS

AF ………………………………………………………………………………... Agroforestry

AFI ………………………………………………………….……… Agroforestry innovations

CFC……………………………………………………………………..…. Chlorofluorocarbons

CO2……………………………………………………………………….……. Carbon dioxide

DOI ………………………………………………………… Diffusion of Innovations Theory

ETB ……………………………………………………………….…Ethiopian Birr (currency)

FAO ......……………………………………………….……..… Food and Agriculture Organization

GDP………………………………………………………………Gross Domestic Product

GOV …………………………….…………………………… Government/governmental

ha...........................................................................................................……hectare

INBAR …………………………….………….. International Bamboo and Rattan Organization

IOT ……………………………………………………………………..…. Internet of Things

IT ………………………………………………………… Information/Internet Technology

MEFCC……………………………… Ministry of Environment, Forestry and Climate Change

NFSDP ………………………………………... National Forest Sector Development Program

NGO …………………………………………….……….…. Non-governmental Organizations

SC ……………………….…………………………………………………. Social Capital

SSA ……………………….……………………….……...…………… sub-Sahara Africa

TAM …………………………………………………….….…… Technology Acceptance Model

TPB …………………………………………………….…..…. Theory of Planned Behavior

TRA ………………………………………………….…..……… Theory of reasoned Action

USD ……………………………………………………………….….…United States Dollar

UTAUT ……………………….….… Unified Theory of Acceptance and Use Technology Model

WB ………………………………………………………………………………. World Bank

# 1. INTRODUCTION

## 1.1. Agroforestry in Ethiopia

Ethiopia, situated in the horn region of Africa, is a country of more than a 117million individuals (WB 2022). The nation aspired to achieve middle-income country status by 2025 (Aynalem 2019). Based on some sustainable development goals parameters like poverty reduction, and improved health systems, the country is on track to achieve its goals. There are also noticeable advancements in the manufacturing sector as the government continues establishing various industrial zones (such as manufacturing and food processing) in different parts of the country (Zhang 2018). Of course, growing political strife and rift also influenced and resulted in unsteady growth in all sectors of the economy. Despite growing criticism as an incorrect parameter, the GDP of Ethiopia is one of the lowest and is around US$944 per capita (WB 2022).

The service and agricultural sectors are the major economic sectors with the highest employment and production volumes. Agriculture employs more than 80% of the labor force and contributes the largest share of economic output as other economic activities (e.g., marketing, processing, export) depend on it (Zerssa 2021). The performance of the agricultural sector, however, remains largely unsatisfactory. Nonetheless, the development endeavor of the country is intertwined mainly with smallholder-focused economic advancement policies and practices (Mellor and Dorosh 2010).

According to recent estimates, forests cover 15.7% (17.35 million ha) of the Ethiopian landmass (MEFCC 2018). In Ethiopia, a forest is a land with trees (natural or planted) attaining a height of more than 2 meters at maturity, canopy cover of more than 20%, and covering an area of more than 0.5ha with a minimum width of 20 meters (MEFCC 2018). Estimates of the national forest coverage considerably vary according to sources. Former appraisal of the forestry sector had underestimated its contribution (2.3% of the 2015 GDP) to the national economy of Ethiopia (MEFCC 2018). Recent accounting and re-accounting by Yadeta and Ayana (2020) revealed that the contribution of the forest resources could be around 8% of the national GDP of Ethiopia, an increase of 5.7% from the government report of 2015. Despite debatable national accounting and reporting systems (such as assimilation with other sectors), the forestry sector's contribution to the national economy is unquestionable. Its contribution becomes even more noticeable with the expanding local furniture sector (Tolera et al 2021).

Commercial plantations, agroforestry (AF), agroforestry innovations (AFI), and AFI woodlots are the foremost forestry resources. AF is a land-use system in which woody perennials are integrated deliberately into land management with crops and or animals in some spatial arrangement or temporal sequence (FAO 2020). AFI are all tree and/or shrub species planted or adopted and consciously managed by farmers, business people, and organizations in their homesteads, farmlands, grazing lands, degraded lands, residences or offices, and or commercial plantations.

AFI production is part of the agricultural sector and is a traditional practice of smallholder farmers in Ethiopia. AF is a traditional practice by smallholders as farmers continuously retain trees on farm plots (Amare et al. 2019) and grazing lands (Jiru 2019), establish home gardens (Bantihun and Abera 2019), plant shade trees (Belay et al. 2019) and woodlots (Nigussie et al. 2017). Although the different AFI forms are found abundantly in the country, there are cases where some are very common to specific geographic contexts of the country. For instance, Endale (2019) acknowledged three types of AFI productions: pasture land, farmland, and home gardens in Northwestern Ethiopia. Coffee shade trees are common in the country's southern and southwestern parts. While the home garden is found commonly in Ethiopia, fruits-based home garden AF is found primarily in southern Ethiopia. According to Birhane (2014), AFI production is an alternative and possibly cheaper option for agricultural intensification and sustainability in Ethiopia. Its importance extends from increasing productivity, restoring the productive capacity of degraded lands, and securing food requirements to improving rural income, protecting biodiversity and environmental services, and supporting climate change adaptation efforts of the rural population (Birhane 2014).

Due to the rampant market and environmental conditions that marginally align or fit household needs, farmers have been increasingly practicing different forms of AFI as complementary to primary crop-livestock production or as their primary production system (Wondie and Mekuria 2018). The establishment of AFI tends to follow consumption needs, cash generation goals, natural resource management aims, and securing food and feed services, including environmental amenities. Depending on the purpose, farmers practice AFI either traditionally (i.e., in small amounts around homesteads or border plots) or on large scale plantations (e.g., woodlots). Enlarging tree-based AF land use practices under different landforms is the alternative method of increasing the efficiency of land (Birhane 2014).

In addition to these traditional practices, extension services and donor projects introduced a large variety of modern AFI in the context of rural development and environmental rehabilitation programs and policies (e.g., Ajayi et al. 2011). Nevertheless, the adoption of these AFI remains low for various reasons (Partey et al. 2017; Mercer 2004). Along with the absence of a pluralistic extension system that addresses the different needs of various target groups (Mbow et al. 2014; Lubell et al. 2014), low dissemination of AFI in SSA is ascribed to the marginal uptake of the results from AFI adoption studies by development interventions (Glover et al. 2016).

Besides other components, there is a government interest in increasing the forest sector for CFC mitigation to 138 million tons of CO2 annually and its impact to 159.8 million tons of CO2 annually (MEFCC 2018). NFSDP (MEFCC 2018) outlines the masterplan that serves as the roadmap for future forestry actions across sectors. The government's primary focus on the forestry sector is due to its role in achieving a climate-resilient green economy (MEFCC 2018). Of course, the government aimed to increase the GDP contribution of the forestry sector to 8.3% by 2020 (MEFCC 2018). The NFSDP identified the huge wood supply gap compared to the growing demand that might lead to the deforestation of an additional 9 million ha of natural forests between 2020 and 2030. The document also highlights shortages in human and institutional capacity in the sector. Given the tremendous potential of the forestry sector, the government aspires to foster professionally managed commercial plantations (MEFCC 2018). So to aid the government's plan of overhauling the forestry and AFI sector, there is a need to provide robust foundations. These foundations can be drawn mainly from discussions with stakeholders, articulation of lessons, and field assessments from representative communities. Consequently, this project aimed to provide rigorous recommendations to support this transformation of the current forestry and AFI sector. It helps to transform the current traditional or unplanned development interventions into a more structured and planned sector where policy design and development planning are undertaken based on scientific evidence, and the sector serves as a primary or an alternative enterprise for income generation. We, therefore, aspire to support the fruitful implementation of the forestry sector master plan of Ethiopia by generating lessons from farmers and previous research.

**1.2. Problem statement**

Farmers consciously establish AFI. The multiple merits of AFI (i.e., environmental services, financial products, and social goods) are well-known and widely recognized (Jose, 2009; Jamala et al. 2013). Farmers have detailed knowledge of the farming environment, their AFI needs, and practice (Alteri 2004). However, smallholders' knowledge of the benefits of AFI stratifies from that of experts (Jerneck and Olsson 2013; Amare et al. 2016; Amare et al. 2017). AFI practices of smallholders are highly complex, dynamic settings with different intensities, productivity, and capacity (Harrington and Tow, 2012). Their AFI plots and systems exhibit diversity in plant composition, arrangements, and stand densities (Nair 2011). The benefits drawn vary decisively as plant performance and utility are location specific depending on farmers' needs, conditions, and knowledge (Reubens et al. 2011; Amare et al. 2017).

Despite farmers' knowledge of the potential benefits, AFI are generally poorly adopted (Fekadu et al. 2014). Different researchers have put forth various explanations for the low adoption. Researchers cite system and farm-level constraints as reasons for the low adoption of AFI practices. For example, Hekkert et al. (2007) stated that the effectiveness of innovation systems functions is crucial for innovation adoption's success.

Research has identified numerous barriers to adopting innovative farm technologies (Russel and Franzel 2004; Harrington and Tow, 2012; Fekadu et al. 2014). Traditional formal research systems have often failed to recognize this diversity in needs and frame conditions among farmers (Leeuwis and Van den ban 2004). Successful AFI adoption requires the development of locally adapted technologies (Cramb 2016) and the integration of innovation with rural livelihoods and gender (Mbow et al. 2014). Ensuring the compatibility of AFI to the agro-ecology of the target farming system and area facilitates adoption (Raffael et al. 2015). Creation of an enabling environment for business development (Russel and Franzel 2004; Avelino and Rotmans 2009; Sood et al. 2008; Jerneck and Olsson 2013), stimulation through effective investment promotion incentives (Russel and Franzel 2004), and articulation of enabling policies and institutional environments has shown fruitful AFI adoption of smallholders across the world (Sood et al. 2008; Richards et al. 2013; Raffael et al. 2015).

Further, the expansion of market opportunities for smallholder AFI products facilitated the adoption and diffusion of AFI (Russel and Franzel 2004; Hekkert et al. 2007; Richards et al. 2013; Mbow et al. 2014). The technology transfer mechanism is the backbone of agricultural technology adoption. The failure of the traditional extension system to address the needs and interests of widely scattered smallholder farmers with different contexts is one of the major causes. Devising appropriate extension methods (Kiptot et al. 2006; Darr 2008; Coe et al. 2014; Fekadu et al. 2014) that work for the different sections and areas of the smallholders (Richards et al. 2013; Smith and Mbow, 2013; Raffael et al. 2015), redesigning the knowledge transfer (Lubell et al. 2014) as locals can also be innovation sources and developing effective scaling up ways (Richards et al. 2014; Smith and Mbow 2013) are crucial for effective AFI adoption targets.

Generally, AFI practices are not yet widely adopted in Ethiopia. The absence of formal advisory services, the previous disintegrated efforts of AFI interventions under different institutes, poor resource mobilization, and predominantly degraded area-focused AFI interventions are justifications for low adoption. Of course, promoting forestry and tree management technologies in Ethiopia has been pursued primarily through campaigns, which were of limited success. A formal forestry advisory service system that delivers adapted tree management technologies to rural smallholder populations still does not exist. Available agricultural innovation delivery mechanisms are of limited use to promote the adoption of AFI owing to their complexity and higher risk involved.

Negligible focus assumed to the AFI sector is another imperative reason for poor adoption. Birhane (2014) even indicated the poor attention given to AFI production by the Ethiopian government by labeling it as an 'orphan' enterprise. The government and relevant stakeholders have admitted this underprivileged status of AFI in resource mobilization (MEFCC 2018). Acknowledging the importance of different types of AFI systems, the government of Ethiopia has established AF as a separate department under the newly established MEFCC and its research wing, the Ethiopian environment and forest research institute (Birhane 2014). This establishment coordinates and consolidates the disintegrated efforts that shape farmers' incentives to manage AFI investments. It also coordinates the strategic development of AFI and enhances its intensification.

Researchers and various reports pronounced less attention by the government and the absence of market value as the ultimate causes for the negligible uptake of AFI. Overall unplanned, campaign-dominated, and haphazard or unscientific AFI development and promotion approaches resulted in botched resource mobilization efforts for AFI interventions. Masterplan designed by MEFCC (2018) stated that forestry expansion to private lands and incorporation as a business opportunity remains scant and haphazard to fulfill the goal of a resilient green economy. Consequently, researchers repeatedly stressed the need to study the Ethiopian AFI system (cf. Richards et al. 2014; Smith and Mbow 2013).

Adopting AFI is an intricate process of implementing, adapting, making, re-making, trying, expanding, reducing, and or abandoning. Smallholders' AFI adoption continues to be a complex decision-making process of resolving alternatives and the environment. Farmers' contexts, system-level conditions, and intrinsic features of the AFI usher these complexities. Based on the biophysical context, home consumption needs, market opportunities, prevalence of alternative products, and availability of viable alternatives or supplies for further needs, farmers make decisions of capricious extent and diversity at different periods. Adoption decision-making is a very complex context that is difficult to understand easily in a single research.

So, this project is initiated to more inclusively explore the factors influencing AFI adoption under smallholder contexts. Accordingly, there is a need to understand both farm-level and system-level barriers in order to identify the major bottlenecks of AFI adoption by smallholders. Hence, this proposal aims to investigate (a) farm level, (b) system-related, and (c) innovation-linked factors that influence the adoption of AFI practices by smallholders.

### 1.3. Objectives and research questions

Field and desk studies are required to fill the knowledge gap related to the factors influencing the adoption of AFI in light of the continuing knowledge gaps and the desire to comprehend better the challenges related to the adoption of AFI. Regarding desk or literature studies, we aim to understand the broader adoption concept and the current information on the adoption of AFI and associated suggestions. For the field work, we aim to employ a more comprehensive field work that responds to the knowledge gaps and suggestions specified by previous research. Thus, the main objective of this study is to investigate the factors influencing the adoption of three selected AFI systems in Ethiopia. The following specific objectives are set to achieve the main objectives of this study:

1) Synthesize current AFI socioeconomic studies in SSA
2) Investigate household contexts that influence AFI adoption
3) Examine the influence of innovation characteristics on AFI adoption
4) Analyze the effect of system-level features on AFI adoption

To achieve these objectives, the following research questions (RQ) are formulated:

RQ1: What is the current status of AFI adoption studies, and what do they suggest? What progresses exist? What does the broader adoption concept recommend?

RQ2: What specific farm level, both the family and the resources around, factors influence the decision either to adopt, increase or abandon?

RQ3: Do psychological factors matter in making AFI adoption decisions?

RQ4: What is the most critical innovation attribute that either attracts or pushes away farmers from making AFI adoption?

RQ5: What system-level factors primarily influenced the AFI adoption decision (adopt, abandon, maintain, reduce) of farmers?

### 1.4. Scope of the study

Attempts continue to provide recommendations to improve agricultural and AFI adoption. Nevertheless, the delivery of actionable recommendations that affect policy and action is limited, as verified by incorporating these recommendations in the continuing development efforts. Calls persisted in conducting rigorous research to improve the moderate changes in SSA adoption of AFI through an improved understanding of the contexts influencing the adoption of these innovations. Despite a plethora of research outputs, this dissertation is the first of its kind, to the best of our knowledge, both in SSA and the world, as well as any sector that tries to understand the complete set of activities and factors affecting the adoption of AFI in Ethiopia. As part of the persistent calls, we learned from previous studies. We developed a better framework that helped as a foundation for understanding the various perspectives affecting the adoption of AFI. Ultimately, we did fieldwork based on this framework and tried to understand the factors affecting AFI adoption by smallholder farmers, using traditional approaches, engaging robust analytical tools, and employing the grandest of factors. From the thematic analysis of the contexts, we employed various econometric models and conducted profitability analysis tools and Bayesian belief networks. Beyond understanding preceding actions, we attempted to predict future adoption likelihood using the Bayesian belief network. In the process, it required the use of time series data. Due to the unavailability of panel or time series data, the study has to depend on a retrospective data set. However, the information generated from this research has meaningful academic, policy, and development benefits or implications. Ultimately, future studies aiming at improving the livelihoods of smallholder farmers by the provision of critical recommendations that indorse the path of development actions and policy frameworks are suggested to adopt the framework and undertake studies both at granular but thorough levels and at grand or holistic scales and employ more systematic approaches and robust tools.

## 1.5. Dissertation structure

This dissertation is organized under five core chapters. The first three chapters briefly familiarize the readers with the backgrounds and the needs for undertaking this particular study and the research protocols followed for conducting both the field and desk work. Chapter four concerns the study's results as outcomes, discussions, and reflections. The remaining chapter presents synthesis and reflections based on the research objectives and describes their implications. The contents of each chapter are described below, with the schematic diagram (Figure 1) displaying the integration among components.

**Chapter one** introduces AFI production in Ethiopia, the problem associated with improved AFI practices, research objectives and questions, scope and structure of the dissertation.

**Chapter two** provides a detailed highlight and background on existing analytical and conceptual frameworks employed while assessing the adoption of innovations, suggests the need for developing an adapted framework that briefly addresses smallholder contexts, and introduces a 'newly' adapted framework from the literature.

**Chapter three** pinpoints the research designs employed for undertaking the different chapters of this dissertation. It features the geographic area, data collection, and analysis methods employed.

**Chapter four** presents the results of this research. It compiles two published articles and five unpublished chapters that constitute the research results.

**Chapter five** presents a synthesis of scenarios depicting the approaches and frameworks deployed in our study in contrast to the most prevalent adoption studies and commonly used frameworks. Furthermore, it also summarizes the research findings, responds to the research questions, and briefly states the implication of the research output in academic, research, and policy contexts.

The results are subdivided and presented under three sub-sections: the review and discrete analytical investigations. The review section (chapter 4.1) presents an overview of current knowledge related to adoption in general and AFI adoption under smallholder contexts in SSA, identified gaps related to adoption research, and later concludes by developing a conceptual framework for the field work.

The second section presents the findings from discrete investigations (chapters 4.2-4.5). Based on the literature review, these discrete investigations narrate the results from the individual examination of separate categories of variables and their influence on the adoption of AFI. Discrete investigations comprise analysis of the influence of farm level factor, psychological, institutional, and innovation attributes variables.

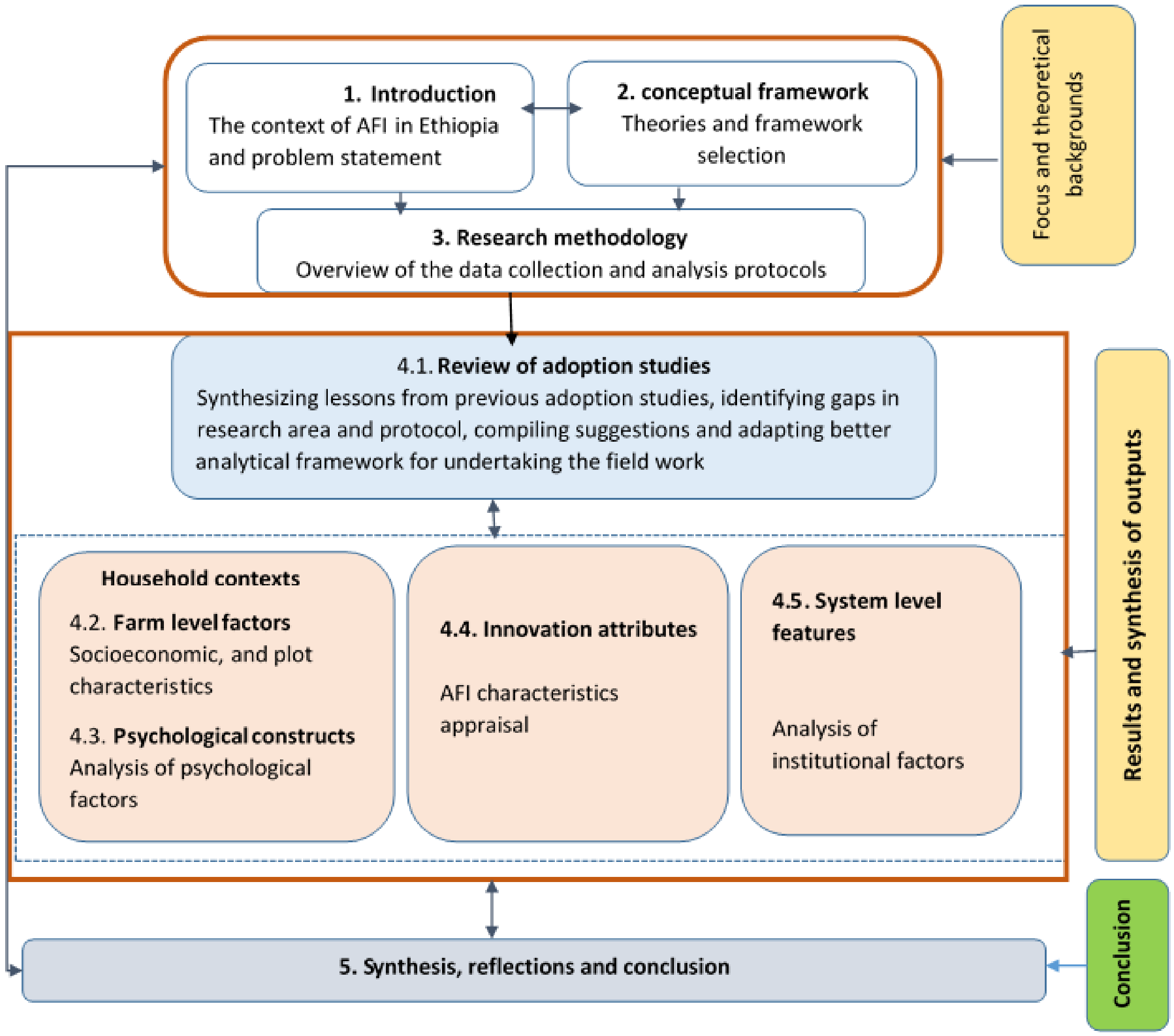


Figure 1. Outline of the dissertation

# 2. CONCEPTUAL FRAMEWORK

## 2.1. The adoption concept

Adoption is a broad concept depicting an individual's acceptance and the positive decision to use innovation (Rogers 2003; Taherdoost 2018). It usually starts with recognizing a need related to the specific innovation that later moves to searching for solutions and attempting or proceeding with implementation (Wisdom et al. 2013). The adoption of innovation is frequently not initiated by the farmers. Development practitioners and policymakers introduce specific innovations aimed at improving the farmers' livelihoods, increasing their productivity, and or increasing the commercialization orientation of farmers or for specific targets such as improving climate change adaptation, managing natural resources, and spreading over or reducing risks. We can comprehensively define adoption as using a particular innovation by an individual farm household (Amare and Darr 2020).

Often the concepts of innovation and diffusion are synonyms with adoption. Innovation refers to technology, knowledge, or practice perceived as new by a community. Nevertheless, it may not be new but relatively recently introduced into the locality. Concerning diffusion, it represents the spread or dissemination of innovation across communities or social groups (Rogers 2003; Mercer 2004). Commonly it is described as community-level adoption.

Understanding the contexts by which the adoption of AFI occurs is essential to appropriately direct development efforts, identify the critical factors and contexts influencing farmers' decisions, foster the effectiveness of development efforts, improve farmers' productivity and production, and facilitate the organization of activities and resources. Despite carrying out various adoption studies, researchers' approaches and actions overlook the complexity of the adoption process and mainly focus on the final users. However, systematically exploring the entire activities and resources involved during adoption, from innovation development to final implementation, is essential for a better understanding of the contexts under which adoption takes place (Panzano and Roth 2006). Researchers suggested different theories and frameworks that support such meaningful exploration, which are discussed below.

## 2.2. Theoretical frameworks on adoption

Related to adoption, in the quest to understand what dictates voluntary adoption of AFI, researchers and academicians have come up with various frameworks (please check these articles for a thorough review of the theories: Hillmer 2019; Koul and Eydgahi 2017; Taherdooost 2018; Wisdom et al. 2013). Among them, the diffusion of innovations theory is widespread.

Diffusion of innovations theory (DOI), coined by Rogers (1962), states that adopting agricultural technologies follows specific procedures and takes place under five stages. Farmers pass these five stages of knowledge creation, forming an attitude, deciding to adopt or reject, implementing, and confirming by communication channels among the members of a similar social system over time (Rogers 2003; Sahin 2006; Bakkabulindi 2014). DOI is the most extensively employed adoption theory as a background for many studies across sectors and innovations (Taherdoost 2018; Kim and Crowston 2011). The theory explicitly states that characteristics of the innovation, the individuals, and the organizations affect the final adoption of an innovation. However, the adoption rate depends on innovation attributes; relative advantage, compatibility, complexity, trialability, and observability.

Amid the continuing employment of this theory as the principal adoption proposition, researchers continue to debate its sufficiency for veritable assessment of the adoption process and suggest moderate recommendations and even application of advanced perspectives and frameworks (e.g., Glover et al. 2016). For example, Taherdoost (2018) criticized DOI's poor explanatory power and humble practical applicability for predicting outcomes especially compared to other adoption models. Further negative criticism towards DOI includes assumptions about innovations as static objects, oversimplification of the complex adoption decision, and ignorance of the integration among different actors or factors (Hoffman 2007). Besides DOI, academicians developed and employed other theories that presumably explain the adoption of various innovations. Behaviorist theories such as the theory of reasoned action (TRA), theory of planned behavior (TPB), technology acceptance models (TAM), and unified theory of acceptance and use technology (UTAUT) are the second most frequently employed theoretical frameworks, after DOI.

Initially developed for socioecological and psychological research, TRA by Fishbein and Ajzen (1975) is often employed in adoption research. Typically, TRA conceptualizes adoption and use intention as a major outcome variable influenced by various preceding or independent variables (Kim and Crowston 2011). TRA's basic assumption lies in the presumption that a farmer's behavior (e.g., adopting AFI) is determined by his or her intention to perform the behavior and that this intention is, in turn, a function of his or her attitude toward the behavior and subjective norms (Fishbein & Ajzen, 1975). Attitude is an individual's evaluation of an object, subjective norms are perceptions about the immediate community, belief as a link between an object, and some attributes and behavior resulting from intention (Fishbein & Ajzen, 1975). In TRA, stronger intentions lead to increased effort to perform the behavior, ultimately increasing the likelihood of behavioral performance. TRA is appreciated for explaining the logical link or absence of a relationship between different background factors and a given behavior. Despite the increased application of TRA in IT sectors, it is criticized for the poor incorporation of the role of habits, the risk of confounding between attitudes and norms, and the assumption of free immediate action (without limitation) once an individual forms an intention.

Due to the above limitation, Ajzen (1991) added the perceived behavioral control aspect in the original TRA framework and proposed TPB. By incorporating this variable, Ajzen (1991) improved the previously faulty assumption that an individual's actions are entirely volitional. TPB (Ajzen 1991) proposes that an individual's actual intention and behavior can be fairly predicted from his or her positive or negative views towards the innovation (i.e., attitude), subjective norms (i.e., perceived pressure from significant others toward the Behavior), and perceived behavior control (i.e., the perceived own capability to successfully implement the behavior). A few behavioral-oriented AFI adoption studies applied and proved the worthiness of the parsimonious TPB (e.g., Amare and Darr 2022; Buyinza et al. 2020). TRA and TPB are employed to understand farmers' voluntary behaviors by examining the basic underlying motivations to act (e.g., adoption). TPB is credited for successfully explaining and predicting behavioral intentions and actual behaviors. Yet, the major weakness associated with TPB is the assumption that individuals are always logical or rational and hence ignorance of emotional decision perspectives. Regarding AFI, applying TPB as a major analytical framework disregards holistic assessment opportunities as it represents a very shallow perspective of AFI adoption influencing contexts and entirely focuses on analyzing individual adopters' behavior. TPB is, however, employed in our research to explore psychological factors affecting AFI adoption.

TAM is another extension of TRA. TAM (TAM 1 and TAM 2) replaces TRA with the assumption that two primary factors influence a farmer's intention to implement an innovation, perceived ease of use and perceived usefulness (Davies 1989). Perceived usefulness represents a farmer's subjective likelihood that the use of a specific innovation will improve his or her action, and perceived ease of use refers to the degree to which the farmer expects the target innovation to be effortless (Davis 1989). The farmer's belief, however, can be affected by external factors. Based on this theory, if a farmer intends to act, then he or she will be free to act without limitation. In the real world, however, several factors beyond these two factors influence such action; hence, this assumption is largely misleading.

Later, Venkatesh and Davis (2000) proposed TAM2. TAM2 imagines that individuals' mental assessment of the match between important goals at work and the consequences of performing job tasks using the innovation serves as the basis for forming perceptions regarding the usefulness of the innovation (Venkatesh and Davis 2000). The results revealed that TAM2 performed well in voluntary and mandatory environments. Researchers publicized the application of the TAM2 theory by introducing further modifications and amendments. Often employed in IT settings, the theory is criticized for its limitation for not addressing the use of innovation in business and organizational contexts and its main focus only on the individual's perception and purpose. Researchers (e.g., Ajibade 2018; Chuttur 2009) indicated a lack of rigor and suggested modification to improve its limitations. Overall, TRA and its extensions, namely TPB, TAM1, and TAM2, relate only to a presumed consumer's or adopters' or individual's behavior and marginally describe prior innovation development, delivery, and innovation attributes. Because of this direct and detached application of these behavioral frameworks, assessing the adoption of AFI greatly diminishes the complex context related to innovation adoption and factors affecting individual farmers' adoption behavior, including but not limited to the environment, public services, and the collaboration among stakeholders.

Beyond marginal modifications (Jerneck and Olsson 2013), researchers have recommended a complete overhaul of the existing adoption frameworks to understand the adoption process better. Consequently, researchers across disciplines and sectors have come up with diversified or improved versions of various frameworks and attempts to build a single comprehensive theory. One such theory is the Unified theory of acceptance and use technology (UTAUT)**.** UTAUT is a combination of eight theoretical frameworks as a comprehensive theory. Formulated by Venkatesh et al. (2003), it brings together alternative views on user and innovation acceptance with four core constructs as the direct determinants of intention and actual behavior. Performance expectancy, effort expectancy, social influence, and facilitating conditions are the four constructs (Venkatesh et al., 2003). These constructs are, in turn, moderated by gender, age, experience, and voluntariness of use of individuals. Commonly employed in the IT sector, UTAUT is verified to be superior based on variance explanation power compared to its foundational theoretical frameworks (Williams et al. 2015). UTAUT is criticized for research outcomes with poor generalization prospects and a primary focus on behavioral analysis. Various extensions were introduced to improve its efficacy. Despite improper application and reduced explanatory power by studies employing the model, Dwivedi et al. (2019) suggested a revised framework incorporating attitude.

Another framework developed from innovation contextualization is innovation functions (Hekkert et al. 2007). Hekkert depicts the adoption of innovations as a process fulfilled by completing seven functions. As stated, 'functions of innovations', are the building blocks for the effective adoption of new innovations and overcoming incumbent innovation systems. These functions are entrepreneurial activities (function 1), knowledge development for innovation generation (function 2), knowledge diffusion (function 3), the guidance of the search (i.e., visibility and clarity of specific wants among technology users; function 4), marketing function (function 5), resources mobilization (function 6) and creation of legitimacy or counteract resistance to change (function 7). The framework is developed initially for manufactured goods, particularly in adopting renewable energy sources (Hekkert et al. 2007). Researchers such as Tigabu (2017) tested it for evaluating the adoption of biogas energy in developing countries' context. Despite the importance of the framework for evaluating the adoption of diverse innovations, its applicability to smallholder farmers is problematic. The critical point for such a problem is that the framework primarily focuses on innovation. Of course, it tries to address the adopters or farmers by loosely depicting farmers as entrepreneurs, knowledge disseminators, and lobbyists. All the functions relate to business enterprises and big institutions with massive research and development and lobbying capacity. Mapping these functions under smallholder contexts is of no use given the marginal involvement of farmers in research (e.g., adaptability tasks). In addition, the innovation depicted in the framework is mainly unaffected by environmental features. In the case of AFI, the environment plays a substantial role in the productivity and performance of the specific innovation. Employing this function of innovations framework as a foundational conceptual base becomes implausible. Indeed, our context, adoption of AFI under smallholder farmers, departs from the research contexts of these functions of innovations framework. Smallholder farmers represent a sizeable rural population residing in the developing world, mainly in Africa, Asia, and Latin America. Their specific context relates to a complex environment, mainly consumption-based agricultural or AFI production. Behaviorally, these huge populations exhibit risk avoidance behaviors, poor resilience, and unsophisticated farm operations. So, a framework that focuses equivalently on the smallholder farmers' contexts (i.e., their resources and socioeconomic status) fundamentally affected by environmental factors is more relevant than frameworks mainly depicting innovation.

Plenty of other bodies of theoretical frameworks and their extensions exist and are applied across management, agriculture, IT, and health sectors (Ute 2019; Taherdoost 2018; Wisdom et al. 2013). Moreover, it is up to the knowledge and preference of researchers and the contexts (e.g., AFI) to select or adapt a theoretical framework for application in the adoption analysis.

### 2.3. The critique and research context

Amid the difference in the technological perspectives, DOI has served as the basis for building up the framework of most adoption studies due to the incorporation of a larger domain of variables such as institutional and innovation attributes and the focus on the adoption decision instead of an individual's behavior (Hoffman 2007; Hillmer 2019). Despite the application of DOI in AFI adoption research, the studies fail to incorporate the many features of DOI. Quantitative studies prominently focus on investigating socioeconomic factors at the adopter's level. Qualitative studies that employ DOI concepts also focus on institutional factors. Consequently, it is hardly difficult to find studies that comprehensively investigated the adoption of AFI by employing the innovation attributes, institutional factors, and factors at the farmer's level.

Beyond the full incorporation of DOI concepts for adoption studies, correcting the limitations associated with DOI (e.g., Hoffman 2007; Meijer et al. 2015; Glover et al. 2016; Harrison and Herbohn 2016) such as (i) the absence and necessary inclusion of intrinsic (psychological or behavioral) factors, (ii) the visualization of adoption as a process and fluid assembly of decisions, not static concepts, (iii) the integration among factors and or stakeholders and (iv) visualization adoption as the concept of a system is essential. In this study, we incorporated these concepts to develop a comprehensive analytical framework during the review process for the fieldwork as the research followed an iterative learning and practice approach.

Ultimately, to develop a comprehensive analytical framework for rigorous assessment of AFI adoption, we selected the DOI framework as it relates to our farmers' contexts and comprises many elements necessary for the successful adoption promotion of AFI. Besides, it is essential to amend the gaps related to the DOI framework. In fact, despite the ability to incorporate various variables in the framework, it is generally suggested to make major modifications to incorporate many of the initially ignored variables used in other frameworks and draw a clear connection among the category of variables. In our iterative learning and reflecting approach and intending to adopt a comprehensive framework, we developed the AFI innovation adoption analytical framework dubbed as the framework from the assessment of analytical and conceptual studies.

### 2.4. The AFI adoption analytical framework

Amare and Darr (2020) critically reviewed various adoption studies conducted under smallholder contexts and recent adoption study trends and frameworks. In the process, they summarized, appreciated, and criticized, subsequently developed a comprehensive framework that highlights a holistic view and conceptualizes adoption as a complex and dynamic (i.e., fluid assembly that farmers modify to suit their different needs and capacities) decision process. The framework is ideal, especially for smallholder contexts, as it proportionately focuses on the farmers, the innovation, and system-level features and the integration among these factors for a diligent understanding of smallholder AFI adoption contexts. We applied this framework (Figure 2) to comprehend factors influencing the adoption of three selected AFI in the Amhara region of Ethiopia as a case of smallholder farmer contexts.

In addition to incorporating the integration aspect and holistic view, the AFI adoption analytical framework (hereafter) comprises three major components (Amare and Darr 2020). The framework is built up of (i) DOI, (ii) TPB, (iii) notions of innovation adoption as a fluid assembly, (iv) integration among factors, and (v) a holistic perspective. It depicts the roles of each category and creates a vivid picture of the adoption process. When the framework is depicted as containing DOI, we are referring to the incorporation of innovation adoption perspectives of perceived innovation attributes, institutional factors, and the characteristics of the farmers. Below we briefly discuss the components and integration of the framework.

Perceived innovation attributes are considered one of the three major factors influencing adoption. It consists of the original five attributes of the innovation: relative advantage, compatibility, complexity, trialability, and observability. We added additional constructs such as disinvestment, volition, and performance and subdivided a few to incorporate many distinguishing features of AFI. Whether privately calculated or understood in the relative advantages concept, profitability is also part of the innovation attributes. By labeling innovation characteristics as one of the three major components, we propose that these features, either solely or combined with other categories of variables, influence the AFI adoption decision of smallholder farmers.

A second component of the framework is the characteristics of the adopting farm households. Despite the diversity of details, these characteristics are explored frequently as socioeconomic characteristics. Nevertheless, here the category (labeled as household contexts) consists of two major subgroups. First, we explore farm level factors related to the farmers' socioeconomic features and the biological contexts of the specific plots where AFI adoption takes place. The selection of variables is based on a combination of literature, subjective assessment of the local context (i.e., preliminary feedback), and analytical testing based on expert decisions. Second, this household's contexts are explored by incorporating intrinsic/psychological factors. Despite DOI lacking these features, we amended the theory by incorporating these concepts by borrowing the notions from previous studies and theoretical frameworks. Despite extensions, we embraced the parsimonious TPB (Ajzen 1991) due to the sufficiency assumption that Buyinza et al. (2020) demonstrated.

The third component is related to system-level features. System-level features comprise the factors, institutions, and stakeholders beyond individual adopters' managing capacity. Such factors as advisory services (i.e., whether public or private) aimed at introducing, training, and supervising activities related to the production and processing of the AFI, facilitation of investment capital needs such as credit facilitation, input delivery, and output trading services, market facilitating activities such as locating new markets and price and policy regulations form system-level features. The selection of relevant system-level variables for further quantitative analysis depends on subjective selection based on prevailing contexts and objective selection based on previous empirical studies and literature reviews. With a prospective application of the framework in all sectors of adoption research, the graphical depiction brings a vivid picture of the influence and integration among the factors for a possible preference of appropriate research.

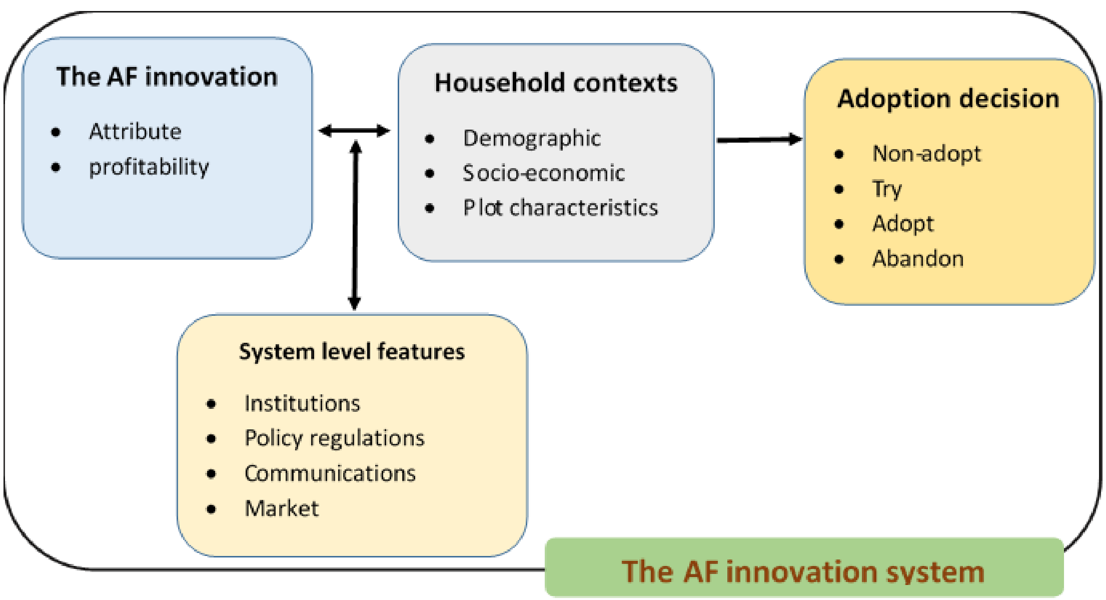


Figure 2. AFI adoption analytical framework (complete description is given under 4.1)

**2.5. Description of links between objectives and research questions**

Rigorous and holistic research approaches and results are exceedingly desired suggestions as understood during the review work. As a rigorous approach to understanding the factors influencing AFI adoption, we conducted both discrete and holistic analytical inquiries. The discrete investigations are undertaken to deliver an insightful understanding of influencing factors. In contrast, the holistic analytical approach is conducted to understand the factors (contexts at large) influencing AFI adoption. Initially, we proposed to understand farm and innovation level factors as rightful approaches. Four objectives are hence proposed for achieving the ultimate goal. During the continuing learning stages, we understood that there are factors inappropriately aggregated under one objective, which required separate investigation for more thoughtful understanding. Consequently, we proposed the six research questions (under 1.4 of the introduction). The links between objectives, research questions (RQ), and the chapters are presented based on the analytical framework.

Objective 1 (synthesize current adoption knowledge) and RQ 1 refer to learning and synthesis of current adoption literature. Analytical results for the objective and RQ are answered in the results section of the dissertation under chapter 4.1. The initial objective 2 is rephrased or approached from two perspectives; (1) farm level factors (socio-economic and plot characteristics) and (2) psychological constructs. Thus, Objective 2 and RQ 2 refer to the part of the household contexts, which we framed as farm level factors. Moreover, this part of the objective and the RQ is replied to under chapter 4.2 of the results section (chapter 4). Further, due to previous suggestions and the availability of appropriate theories, the RQ 3 of objective 2 is answered by doing the analytical results displayed under chapter 4.3 of the results section. Overall, objective 2 is fulfilled by undertaking a proper analytical examination of RQ 2 and RQ 3.

Similarly, objective 3 (influence of innovation characteristics on AFI adoption) is rephrased by RQ 4. Analytically, objective 3 and RQ 4 are responded to under chapter 4.4 of the results section. Similarly, objective 4 (influence of system level features on AFI adoption) and RQ 4 refer to institutional factors influencing adoption are similar expressions, and chapter 4.5 in the results section (chapter 4) provides the analytical results of the query. Further elaboration and reflections on all the objectives are given in the synthesis and conclusion chapters (chapter 5). Ultimately, we deliberate on the existing conceptual framework and our proposed framework in the context of smallholder farmers. Synthesis and summary are given in chapter 5.

# 3. RESEARCH METHODOLOGY

## 3.1. Description of the study area

The study areas are located in Ethiopia. Primarily Ethiopia is selected as the research site due to the accessibility of the country and the familiarity of the student with the prevailing agricultural and AFI system and the farming community. The familiarity facilitates data collection as the student can utilize existing personal and institutional links for organizing field works and data collection activities. Second, Ethiopia, one of the fastest growing economies in the world, is proposed due to its policy of green economy, large smallholder population (around 80% of 117million), climate change proneness, the existence of a variety of socio-demographic and ecological conditions and the potential for AFI practices (WB 2022; Aynalem 2019). Considering some parameters, the national population indices are far from acceptable despite improving economic conditions. For example, the poverty index (population under poverty), life expectancy, population growth rate, GDP growth rate, and population accessing electricity are 31%, 67 years, 2.5%, 5.6%, and 51%, respectively (WB 2022). As a result, among alternative economic activities, the potential for adopting and using AFI for income, climate change adaptation, and ensuring the continuation of ecosystem services delivery remains high (MEFCC 2018).

The Amhara national, regional state of Ethiopia is selected as the specific study locality (Fig.3). The Amhara regional state ($11^{0}$39'39" N $37^{0}$57'28" E) is selected due to the existence of various farming systems, AFI practices, and the variety of motivations and outcomes (Amare and Darr 2022; Nigussie et al. 2020). The region is characterized mainly by a population dominated by smallholder farmers and agriculture as the mainstay of the economy. Among the districts in the region, three districts are selected as specific study sites, namely, Mecha, Fagita Lekoma, and Banja (Table 1). The selection of the districts is due to the large scale production of AFI woodlots (Amare and Darr forthcoming; Wondie and Mekuria 2018; Nigatu et al. 2020). Mecha offers favorable conditions for agricultural production with good soil fertility, slope, and mid-highland climate conditions. Fagita and Banja districts have limited crop diversification opportunities due to poor soil fertility. The AFI selected in this study are farm woodlots of *Acacia decurrens* (hereafter acacia), *Eucalyptus camadulensis* (hereafter eucalyptus), and *Yushania alpine* (hereafter bamboo). Woodlots are an important AF system in Ethiopia that involve a variety of crop-livestock combinations.

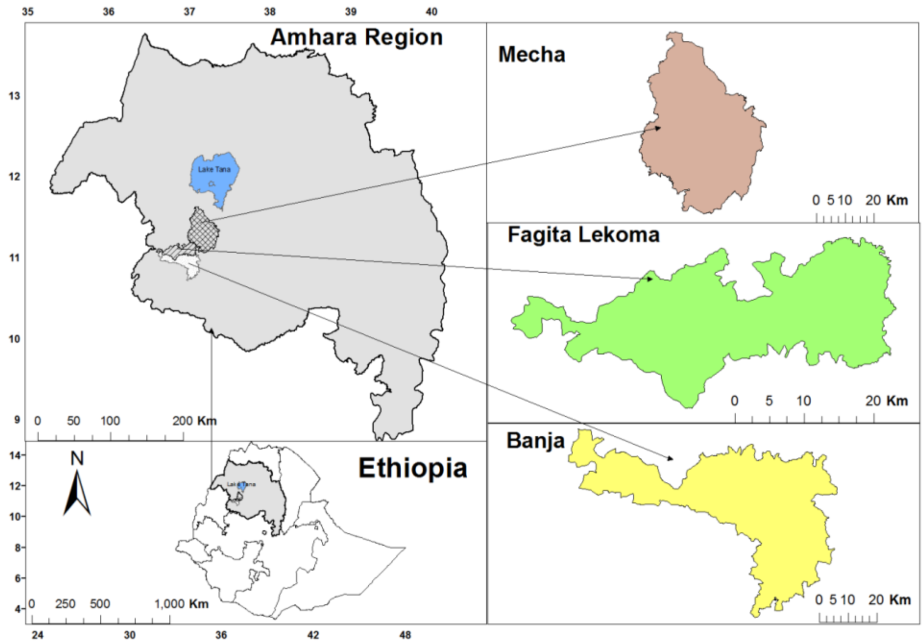


Figure 3. Study area

### 3.2. Selection of innovations and farmers

Woodlots are an important AFI system in Ethiopia that involve a variety of crop-livestock combinations. For example, the trees are inter-cropped with selected field crops when the woodlot is being established, and later livestock can be left to graze between the AF trees, or the grass is harvested as livestock feed (Nigussie et al. 2020). The AFI woodlots explored in this study are acacia, bamboo, and eucalyptus (Table 1). These AFI woodlots represent major investments in Fagita Lekoma, Banja, and Mecha districts. Their dominance is ascribed to a host of factors. Acacia is a fast growing AFI woodlot planted mainly for generating additional income (Nigussie et al. 2020; Wondie and Mekuria 2018). Bamboo is a long-established AFI produced for home consumption and cash generating where its production is not well established and has high market volatility due to unstable demand (Nigatu et al. 2020). Eucalyptus is an exotic AFI tree widely cultivated for its various benefits, including cash generation (Tefera and Kassa 2017). Overall, the selected AFI exhibit diversity and economic and ecological benefits and impacts, and farmers have varied attitudes towards continued production of them (Amare and Darr 2022). Despite the differences in the nature of AFI and the environmental and socioeconomic conditions prevailing in the districts, this study analyzes the three AFI in aggregate because the three practices are sufficiently adapted to the local conditions prevailing in the respective study areas and exhibit similar basic adoption decision making processes and governed by similar contexts. Undertaking research on the three AFI, which involve relatively huge investment capital, particularly scarce land, can provide insightful lessons for future efforts to commercialize AFI away from the traditional natural resource management objective.

Table 1. AFI and their geographic context

| Innovation | Eucalyptus camaldunesis | Acacia decurrens | Yushania alpine |
|---|---|---|---|
| District | Mecha | Fagita Lekoma | Banja |
| Geography | $11^0$ 10’ and $11^0$25’ N & $37^0$2’ and $37^0$17’ E | 10°57′23″ to 11°11′21″N & 36°40′01″ to 37°50′21″E | $10^0$52’00” to $11^0$2’ 44” N & $36^0$38’26” to $37^0$7’8” E |
| Agro-ecology | Woina-Dega, fertile, multi-cropping | Woina-Dega, less fertile, limited cropping options | Dega (cool highlands;80%), very limited crop, degraded acidic soil |
| Support systems/Extension service | No conscious intervention; however seedling was available | Government extension through properly designed commodity app. | INBAR , limited gov extension |
| NGOs/ stakeholders | Interest groups/individual traders | Amhara Development Association | INBAR skills training and promotion |
| Adoption trend | Expanding | Increasing and expanding | Decreasing? No data. |
| Market outlook | Expanding and stable | Expanding but unstable | Marginal and unstable |
| Research Interest point | How market factors alone dictate adoption decision | The effect of committed policy actions with pluralistic extension | How innovation characteristics affect adoption even with relative advantage |

### 3.3. Research methods

The research design for this study is mixed methods and employed both qualitative and quantitative analysis. Both primary and secondary data sources are used to accomplish the study. Primary data was collected using structured and semi structured questions from household interviews, focused group discussions, key informant interviews, and case studies. Further, narrative walks (i.e., observation, photography) in transect sampling (Jerneck and Olsson 2013) were used to explore the spatial, physical, temporal, and social conditions of AFI practices from the in-situ dialogue. The study focused on exploring the factors influencing the adoption of AFI from different perspectives and diverse stakeholders as told and narrated by farmers, local experts, and stakeholders.

#### 3.3.1. Data collection methods

Household survey (interview schedule) is the primary data collection method. In order to collect data to answer our objectives, a household interview schedule was used as the primary data collection instrument. The questions were designed to respond to the various information desired to accomplish the study, including socioeconomic status, AFI adoption trend for the past several years, types of production such as intercropping or sole cropping, AFI profitability related information, support systems and linkages with various stakeholders, price and demand volatility, negative and or positive perceptions about producing these AFI compared to traditional crop production, livelihood contribution and psychological or behavioral viewpoint towards producing these AFI.

Further, nine key informants, three key informants from each AFI system, were enquired to assess the historical knowledge related to the introduction, production and consumption, and marketing of these AFI in their locality. During the selection of key informant interviews, we followed the snowball sampling method as the first interviewee directed us to the next most prospective farmer that offered the best information. This was primarily related to age or years of residence. Additionally, three focus group discussions were conducted that largely reflected the current attitude, challenges, and opportunities related to the production of the AFI. All this information was consolidated and refuted with data collected from publications, reports, workshop proceedings, and manuals. Ultimately a total of three (3) focus group discussions with 9-12 participant farmers (and a total of 32 farmers) were conducted in each AFI system, one in each.

#### 3.3.2. Sampling technique and sample size

A multi-stage sampling procedure was followed for the household survey to select farmers. After the districts were purposively selected, representative Kebeles (lowest level administration in Ethiopia) were selected in each district based on the prevalence of the specific AFI and their importance in the farming systems with input from district experts and heads of the bureaus of agriculture. In consultation with Kebele experts, a sampling frame was prepared for farmers who have at least tried and abandoned the AFI or are practicing or expanding the production of the specific AFI. Thus the sampling frame excludes non-practitioners (i.e., farmers who never tried the production of the AFI). The total sample size was 385 by employing Cochran's (1977) sample size determination formula. Nonetheless, we quit conducting the household interview at the 327 households due to information saturation. Proportion to population size (PPS) was used to determine the sample size from each district. Seven female farmers were interviewed in the absence of their husbands as the rural society is patriarchal.

### 3.3.3. Data analysis

Data analysis employed mixed methods. The methods employed include thematic analysis, descriptive statistics, and graphical flow chart based analysis. Besides, we employed different flow charts depicting the direction of follow-up adoption decisions of the farmers and the possible asset values of the AFI products in a period given the price volatilities of agricultural and AFI commodities. Table 2 briefly displays the data collection and analysis methods employed for each chapter of the results section of the dissertation.

Table 2. Summary of data collection and analysis methods

| Research interest | Indicators | Data collection tools | Data analysis | Analytical level | Research question |
|---|---|---|---|---|---|
| What is the general knowledge on AFI adoption in SSA? | Adoption research trends; limitations; recommendations | Literature review | Meta-analysis; content and thematic analysis | Broad (SSA, global and multiple innovations) | RQ1, Obj.1 (Chapter 4.1) |
| Farm level factors | Socioeconomic, demographic, social capital, plot characteristics | HH, FGD, KI observation | Multivariate multiple regression; content and process analysis | Household | RQ2, Obj.2 (chapter 4.2) |
| Psychological constructs | Attitude, behavioral control, subjective norms | HH | Structural equation modeling | Household | RQ3, Obj.2 (chapter 4.3.) |
| Innovation attributes | The various characteristics of the innovation | HH, FGD, KY, observation | Principal component analysis; structural equation modeling; thematic | Household | RQ4, Obj.3 (chapter 4.4) |
| System level features | Organizational level factors | HH, FGD,KI, observation | Thematic; seemingly unrelated regression | Household | RQ5, Obj.4 (chapter 4.5) |
| Performance of the AFI system | category of factors affecting the likelihood of adoption | HH, FGD, KI, observation | Bayesian belief network (BBN) | Innovation | RQ6, Obj.5 (chapter 4.6) |

*details of each data collection and analysis method are given in each chapter; Obj.=objective, HH=household survey, FGD=focus group discussion, and KY= key informant interview


# 4. RESULTS

This results section compiles and presents two sub-sections

### 4.1. Agroforestry adoption as a systems concept: a review

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**Abstract**

Adoption of innovations is central to improved livelihoods of smallholders and agricultural modernization. The means of achieving optimum adoption rates, however, remain blurred amidst decades of research and interventions. This paper employed both content and meta-analysis to summarize the theoretical and empirical studies conducted in the past three decades in AF adoption practice and research. Literature from innovation, social networks, diffusion, and adoption of innovations streams of research are explored to analyze the main outputs of adoption studies. Positive critique is presented to advance the comprehension of AF adoption decision contexts and improve the effectiveness of interventions. Econometric models employed more than 151 variables to examine AF adoption and information diffusion. Qualitative and descriptive analysis explored further perspectives (e.g., innovation characteristics) complementing the focus on socioeconomic variables in econometric models. The innovation systems concept provided a broader menu of investigation by conceptually integrating a wide diversity of actors and activities thereby increasing our understanding of how such innovations are produced, transferred and adopted across communities, locations and time.

**Keywords:** Africa, diffusion of innovations, extension, innovation systems, technological change

## 1. INTRODUCTION

Adoption of agricultural innovations is central to the development of African agriculture (Glover et al. 2016). Over the decades, numerous programs attempted to make available a large number of tested crop, livestock and mechanization innovations in Africa (Feder et al. 1985; Feder and Umali 1993), yet the desired transformation of the agricultural sector from the adoption of these innovations has yet to happen. Agricultural production in Africa is still dominated by smallholders with little to no use of improved agricultural inputs (Vanlauwe et al. 2014) with few notable exceptions (Bachewe et al. 2018). Numerous studies by rural sociologists, economists, geographers and technologists aimed to explore the causes of low innovation adoption rates among smallholders (Marra et al. 2003); and their findings were expected to provide useful guidance for succeeding interventions (Feder et al. 1985; Feder and Umali 1993). However, these studies have generally contributed only little to revealing the true causes of smallholder innovation adoption or non-adoption beyond long lists of variables associated in some way with the adoption of the innovations under study. Particularly, adoption studies typically fell short of appropriately considering more fundamental questions such as, are the innovations offered to farmers the 'right' ones? Which development paradigm do these innovations convey? And how have farmers been involved in defining priorities and making decisions and adapting the innovations?

Studies on AF adoption employed similar approaches amidst a relatively low AF adoption rate in Africa (Partey et al. 2017). These studies, too, often failed to provide actionable recommendations on how adoption interventions should be improved, which limited the potential benefits to smallholders from scientific and technological advancements (Mercer 2004). Glover et al. (2016) highlighted the flawed conceptual approach underlying most adoption studies as the key reason for their limited contribution to change in African agriculture. Furthermore, recent contributions advanced the conceptual understanding of agricultural innovation systems (Hekkert et al. 2007; Glover et al. 2016). Before conducting further studies there is, therefore, a need to assess the state of AF adoption studies, especially in Africa, in order to more effectively guide future efforts in extension research and practice (Pattanayak et al. 2003).

Review studies on AF adoption are not new but has been a while ago since a comprehensive synthesis was conducted (Table 1). Besides, the incorporation of their feedback by subsequent studies has barely been assessed. Hence, our paper aims to complement the efforts of previous reviews by (i) evaluating the progress of recent AF adoption studies relative to their recommendations; (ii) advancing the concept of AF adoption in line with recent literature; and (iii) formulating directions that will lead to more robust AF adoption studies and interventions. In our review we focused on, and aggregated, various tree cultivation and management practices and innovations from the larger agricultural and AF systems (Appendix A). While other studies have provided more nuanced analyses at the level of individual AF technologies and/or tree species (GYAU et al. 2012), our interest is to trace explanations that hold across a range of various AFI, disregarding to some extent the idiosyncrasies of individual cases and technologies. We employ content analysis as the main review technique to explore the factors that determine the development, diffusion and adoption of AFI in SSA. Further, meta-analysis is employed to obtain a more comprehensive understanding of the factors determining innovation adoption in line with current conceptual and methodological advancements. Finally, we propose a more comprehensive analytical framework, dubbed 'AF innovation-adoption framework', which can potentially guide studies on AFI generation, adoption and diffusion going forward.

## 2. REVIEW METHOD

The utmost effort was made in critically selecting, reviewing and summarizing the relevant literature. The reviewed studies comprised (i) AF adoption review articles, (ii) studies providing conceptual contributions, and (iii) original AF adoption studies. AF review articles published between 1998 and 2017 were included as they well summarized the state of adoption research and identified major research gaps at the respective time of review. Conceptual studies were included to link changing research designs of empirical studies to conceptual advancements of the adoption-diffusion notion. Original AF adoption studies were papers published after 2005, when the last comprehensive AF adoption review (Montambault and Alavalapati 2005) had been published.

Our review focuses on SSA due to the prominent failure of AF and other agricultural technology adoption on the continent. Our interest in SSA was further motivated by the huge potential AF has for increasing the resilience of agricultural landscapes and rural populations in light of climate change, land degradation and socio-economic benefits (Vanlauwe et al. 2014; Dawson et al. 2016). Systematic, best evidence and narrative review techniques were employed to select the studies for our review as follows: (i) employing 29 combinations of relevant keywords (Appendix A), 26,005 research titles were identified from the Web of Science comprehensive database. The search was conducted from 3 to 5 July 2019, while the selection continued until 30 August 2019; (ii) We selected studies that explicitly investigated how socioeconomic related factors influence AF adoption decisions of smallholder farmers by employing standard analytical approaches such as econometric models, ethnographic tools or a combination of biophysical and socioeconomic elicitation methods. Given the sheer number of non-econometric/ non-empirical studies, we systematically selected studies that employed relatively rigorous methodologies and that provided comparatively robust results. Hence, based on the initial screening of titles, 802 AF studies were retained. The other studies were excluded as they did not report findings from Africa, did not primarily address the topic of AF adoption, or did not primarily investigate the socioeconomic implications of AF adoption; (iii) After removal of duplicates, 326 studies were retained;(iv) an abstract and full text assessment of these studies resulted in retention of 58 econometric studies and 24 qualitative (non-econometric) studies, while 204 were excluded as they mostly were descriptive reports that hardly provided consistent information applicable for generalization ; (v) further six AF adoption review articles were included through carefully screening the reference lists of the identified papers and adding further relevant publications (Appendix A).

Based on these steps, 108 publications were finally selected, consisting of 58 econometric and 24 qualitative original articles on AF adoption in Africa, six review studies and 20 further articles making relevant conceptual and analytical contributions to AF adoption studies. Our meta-analysis compiled the results of the 58 econometric AF adoption studies. These models used 151 different factors that were collapsed into 73 distinct variables (Appendix A). Variables designed for smoothening of econometric models like squares of a repeated variable are excluded from the analysis. Qualitative and conceptual studies were appraised by employing content analysis to further explore and incorporate contemporary conceptual and methodological additions or refinements from the wider adoption science. Throughout this paper, we use the term 'innovation' to refer to the various AF technologies and practices in which trees form an integral component. Further, following Rogers (2003) and (Mercer 2004), we define 'adoption' as the use of a particular innovation by an individual farm-household, while 'diffusion' relates to the spread of the innovation across a community or social group.

## 3. RESULTS

### 3.1. Past AF adoption reviews

The review articles illustrate the advancement of the field of study in progressive stages from general to more specific cases but the development was not linear as authors explored issues based on perception of gaps and importance to improved understanding (Table 1). Hence, Mercer and Miller (1998) compiled an overview of socioeconomic AF research primarily published in the *'Agroforestry Journal'* to identify accomplishments, gaps and needs for future research. Pattanayak et al. (2003) emphasized on developing a predictive understanding of how farmers make adoption decisions by producing a meta-analysis of the factors identified in different studies, although they noted the limitations of generalizing due to differences in sample size, geographic location and policy context. Mercer (2004) criticized the application of conventional adoption analysis given the unique features of AF including their complexity and lack of standard AF packages. He rather embraced a broader adoption and diffusion empirical and theoretical work from agriculture to comprehend and integrate how and why farmers make long-term decisions. Montambault and Alavalapati (2005) synthesized AF adoption studies to identify the relative dominance of geographic regions, types of analysis, issues and AFI. Latter, Meijer et al.'s (2015b) explored how intrinsic and extrinsic factors affect AF uptake and how intrinsic factors are less studied. Recently, Partey et al. (2017) assessed and synthesized knowledge on benefits and suitability of bamboo AF.

The recommendations for future research in these studies included more studies on adoption behavior, profitability analyses, non-market valuation, risk and uncertainty and the impact of policies on smallholder adoption decisions (Mercer and Miller 1998); meta-analyses and appropriate measurement and inclusion of credit, savings, prices, market constraints, plot characteristics and innovation specific studies (Pattanayak et al. 2003); the role of risk and uncertainty, how and why farmers modify innovations and factors affecting intensity of adoption including spatial and longitudinal analysis (Mercer 2004); studies on a broader range of economic and social research with both scientific depth and a broad appeal (Montambault and Alavalapati 2005); consideration of both intrinsic and extrinsic factors of AF adoption (Meijer et al. 2015b); and research on bamboo ethnobotany and socioeconomics as well as ecological processes and component interaction (Partey et al. 2017).

Table 1. List and content of AF review studies chronologically

| Authors | Purpose of the study | Number of studies reviewed | Geographic coverage | Time period covered by the studies | Main synthesis method (s) | Main Findings | Identified gaps |
|---|---|---|---|---|---|---|---|
| Mercer and Miller (1998) | Synthesize the progress of under-researched socioeconomic research in AF | 113 | Global | 1982-1996 | Descriptive, vote counting and limited survey from experts | Only 22% of the articles are socioeconomic studies<br><br>Progress on cost-benefit analysis, understanding traditional knowledge, gender issues and factors influencing adoption behavior | Reliance on inadequate sample sizes and ignorance of non-market benefits of AF, insufficient focus on policy, adoption decision making, insufficient economic models and analytical methods, risk and uncertainty |
| Pattanayak et al. (2003) | Identify general determinants of AF adoption | 120 | Mainly the tropics | 1996-2001 | Vote counting, meta-analysis for inclusion and significance of variables | Preferences, resource endowments, market incentives, biophysical factors and risk and uncertainty explain AF technology adoption Preferences and resources are most often included while risk, biophysical and resources are the most likely significant categories of variables | Prevalence of bias towards establishing significance |
| Mercer (2004) | Understand how and why farmers make adoption decisions | 101 | Tropics | 1957- 2003 | Content/qualitative | Progress on use of binary choice models on assessing actual and potential adoption<br><br>Discusses different adoption-diffusion theories<br><br>Narrates AF findings based on Pattanyak's (2003) category of variables | Incorrect treatment of categorical dependent variables as continuous variables and incomplete understanding of multicomponent nature of AF, lack longitudnal analysis, inadequate inclusion of risk and uncertainty |
| Montambault and Alavalapati (2005) | Trend analysis of studies dealing with economic and social issues in AF | Over 500? | Global | 1992-2002, | Descriptive statistics | Increasing trend towards regional and analytical diversity | Temperate regions, riparian buffers, gender & property rights are understudied |
| Meijer et al. (2015b) | Identify the intrinsic and extrinsic factors affecting AF technology uptake | 75 | SSA | 1975- 2014 | Content/qualitative | Existing adoption literature emphasizes on extrinsic factors (adopter characteristics and environment) | Lack of focus for intrinsic factors (knowledge, attitude & perceptions) for AF adoption decision making |
| Partey et al. (2017) | Identify the suitability and benefits of bamboo AF in SSA | 85 | SSA | 1996- 2016 | Content/qualitative | Narrates the benefits of bamboo AF for charcoal, climate change adaptation, fodder, soil conservation, poverty reduction and its compatibility as boundary plantings, windbreaks, shelterbelt or planted fallows | Insufficient knowledge on bamboo AF suitability & benefits |

The continuing suggestions of certain factors like risk and uncertainty confirms that latter research seem to have partially responded to earlier recommendations of these reviews.

### 3.2. Recent (2005-2019) AF adoption studies

#### 3.2.1. General description

Almost all of the studies employed formal household survey as main data collection tool (Table 2). The sample size ranged from 21 to 894 with an average of 240.81 households per model (Appendix A). (Focus) group discussions were also frequently used. Some of the studies were complemented by biophysical or experimental data (Ajayi et al. 2011b; Bucagu et al. 2013) or aerial imagery (Amare et al. 2019). Document analysis specifically policy frameworks (Foundjem-Tita et al. 2013) and project documents (Johansson et al. 2013; Lillesø et al. 2011) were also employed in an effort to understand the various contexts supporting or hindering the adoption of AFI.

Table 2. Data collection and analysis methods

| Data collection method | | | Data analysis | | |
|---|---|---|---|---|---|
| | Frequency | Percent | | Frequency | Percent |
| Household survey | 80 | 97.56 | Content/qualitative | 3 | 3.66 |
| Group discussions | 21 | 25.61 | Descriptive/inferential | 15 | 18.29 |
| Key informant interview | 9 | 10.98 | Quantitative | 6 | 7.32 |
| Case study | 2 | 2.44 | Econometrics | 58 | 70.73 |
| Biophysical data complemented | 14 | 17.07 | | | |
| Field observation | 7 | 8.54 | | | |
| Document analysis | 5 | 6.1 | | | |

With respect to data analysis and specifically econometric models (Appendix A), there was no apparent progress from binary to selection models and more robust panel data analysis models (Figure 1). Instead, models were presumably employed based on the skill of the researchers, and as such relatively simpler binary models were more often used. Along with the complete lack of panel data analysis, the synthesis confirmed that feedbacks from earlier recommendations have been hardly taken into account in this regard.

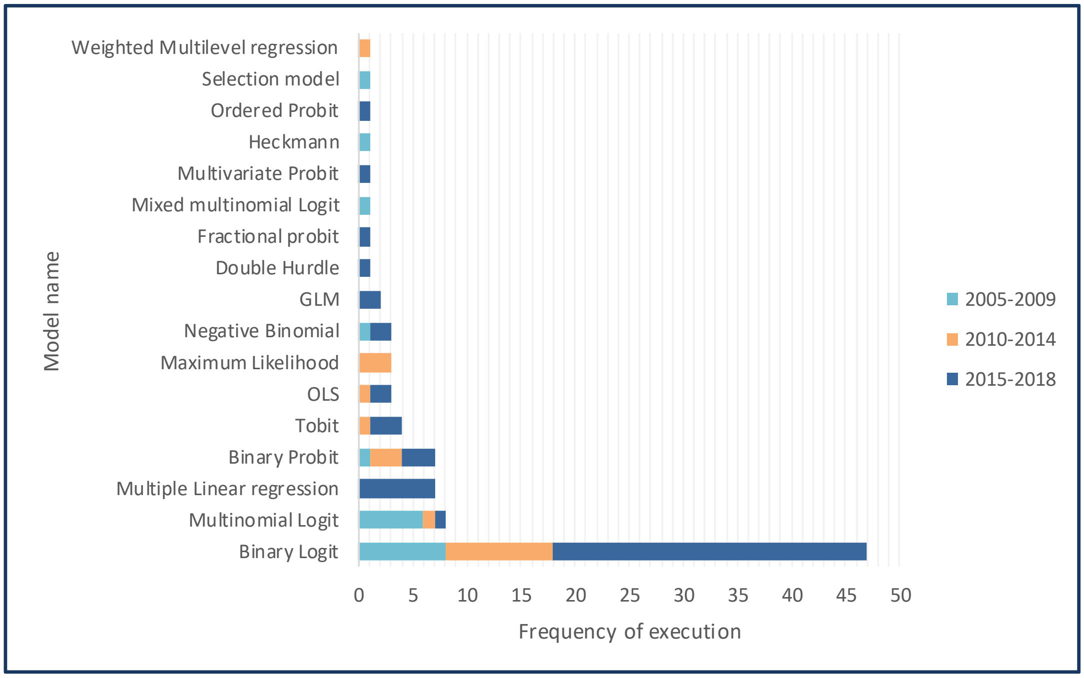

Figure 1.Type of econometric models employed across years by AF adoption studies

### 3.2.2. Continuing narratives on AF adoption

The factors facilitating and constraining AF adoptions identified in the various studies often were overlapping or contrasting across AFI (Appendix A). In order to gain a more comprehensive insight into the narratives presented in the reviewed studies, the factors affecting AFI adoption can broadly be grouped into three categories; namely, the innovation, household contexts, and system-level features. Following, we briefly discuss these categories as derived from content analysis of the reviewed studies (Appendix A).

**The innovation:** Rogers (2003) posited that the attributes of an innovation determine its adoption, an aspect which has since then been reiterated and confirmed countless times in diverse contexts. The perceived characteristic of short maturation period increased the adoption of tree species (Appiah and Pappinen 2010). Higher profitability or use value as manifested by multi-purpose innovations, increased income, or better retail prices typically facilitated innovation adoption while the absence of noticeable revenues impeded adoption (Conteh et al. 2016; Kiptot et al. 2007a). Higher cost of the innovation (Kiptot et al. 2007a) and lower profitability (Sirrine et al. 2010) reduce adoption of AF innovations. Existence of associated non-monetary benefits (e.g., ecological conservation), complementarity to current practice (e.g., with regard to knowledge required, traditions, scale of production) and livelihoods (e.g., contribution to risk reduction or food security), and previous experience with similar practices (e.g., incremental rather than radical innovations) facilitated adoption and diffusion (Gyau et al. 2012). The adoption of innovations with characteristics desired by a diversity of households, and suitable for a broader range of environmental conditions was more intense (Ajayi et al. 2011b). Such diversity matching (i.e., species vs. needs) fostered adoption of AF (Iiyama et al. 2017). Improving the pertinence of AFI to the farmers' needs increased their uptake (Rogers 2003).

**Household contexts:** household context refers to the common AF adoption determinants related to individual farm-household characteristics and the local environment (Ndayambaje et al. 2012; Abiyu et al. 2016). Overall household livelihood strategies determined AF adoption decisions (Ite 2005). Livelihood diversification aiming to minimize risk exposure promoted AF adoption (Gyau et al. 2012), while poverty and the competition of AF investments with immediate livelihood needs constrained adoption (Meijer et al. 2015a; Jerneck and Olsson 2013). Likewise, AF abandonment was low in situations of land abundance, limited competition between tree and agricultural production, and low opportunity cost of labor during the tree production season (Rahim et al. 2007). Furthermore, household social capital supported AF adoption (Sanginga et al. 2006), as it facilitated effective conflict management. Social networks (e.g., participation in community meetings) were positively linked to innovation adoption and dissemination of related knowledge (Iiyama et al. 2017; Amare et al. 2019). Membership in farmers associations also facilitated adoption, while such networks were more effective for technology than knowledge dissemination (Kiptot et al. 2006). Alike extension experts, farmers are important pathways for information about innovations. However, there is disparity in information flow as influential farmers preferred extension information from other influential farmers rather than ordinary community members (Isaac et al. 2007). Also, close relationship between ordinary farmers with innovators (lead farmers) likely enhanced adoption (Toth et al. 2017).

Socio-psychological factors such as the household members' expectations and perceptions also played a role in AF adoption. Incorporating socio-psychological factors (e.g., preferences) into development programs was important to improve the effectiveness of AF interventions (Meijer et al 2015b). Opportunity-seeking behavior motivated AF investment, while risk-evading behavior hampered AF adoption (Jerneck and Olsson 2013). Attitudes and perceived behavioral control were positively associated with tree planting for farmers having tree planting experience (Meijer et al. 2015b). Finally, characteristics of the farm and the local environment were common determinants of AF adoption. Favorable climatic conditions facilitated high-value AF production, whereas poor environments (e.g., marginal lands) were common for farmland AF (Iiyama et al. 2017). Highly fragmented farms (Amare et al. 2019) and steep slopes promoted AF adoption (Iiyama et al. 2017).

**System level features:** Various factors outside the immediate reach of the farm households influenced their AF adoption decisions; including broader environmental and institutional circumstances. With regard to extension approaches, innovations primarily disseminated through group networks in group extension situations while transfer or diffusion of innovations was more effective through casual communication networks under individual extension approaches (Darr and Pretzsch 2008). The most common extension methods, demonstrations, facilitated wider adoption by showcasing their feasibility under farmer-specific conditions (Conteh et al. 2016).

Similarly, capacity building facilitated by extension services, such as training on AF business development skills (GYAU et al. 2012) and AF-based livelihood activities (Owombo and Idumah 2017), increased AF innovation adoption. Farmers' participation in trainings, field days and demonstration plots increased AF adoption (Iiyama et al. 2017; Amare et al. 2019). Likewise, AF systems that were developed locally by incorporating farmers' field experience were better adopted than those brought by outside researchers (Jerneck and Olsson 2013). Continuous adaptation of technologies by farmers during innovation development and implementation improved adoption rates (Ajayi et al. 2011a; Kiptot et al. 2007b). The adoption of an AF innovation by community members induced its adoption by others and reinforced its dissemination in the community (Ite 2005). Furthermore, market features determined adoption outcomes. Lack of planting materials or other market failures constrained AF adoption (GYAU et al. 2012), while the availability of markets for AF products, price premiums, payments for environmental services and further incentives increased AF adoption intensity (Kiptot et al. 2007a; Conteh et al. 2016; Ite 2005). An increasing distance to market centers (Gibreel 2013) also encouraged AF adoption given that farmers had less market opportunities and incentives to produce cash crops.

Policies that addressed constraints such as provision of planting materials and other input, access to credit, provision of subsidies or premium pricing boosted the farmers' willingness to adopt AF innovations (GYAU et al. 2012). Policy actions that redefined the roles of existing support systems, such as institutions and stakeholders, could create more efficient input delivery systems and hence led to better adoption (Lillesø et al. 2011). Effective regulations and enforcement mechanisms were important to maintain and further promote farmland AF practices (Amare et al. 2019). Trust in land policy and land tenure security motivated on-farm tree planting (Owombo and Idumah 2017). Frequent changes in institutions, however, hampered large-scale AF adoption (Ajayi et al. 2011b). In addition, partnership and coordination of farmers and innovation system stakeholders, such as researchers, extension agents, input traders, NGOs, processing companies facilitated smooth exchange of innovations and feedback that was crucial for long-term innovation adoption (Ajayi et al. 2011b; Johansson et al. 2013). Further, partnerships for infrastructure development to facilitate transport and trade of AF input and produce along with technological innovations aimed at developing or adapting AFI for different contexts and needs (Ajayi et al. 2011b) advanced AF adoption.

Altogether, the studies enlisted various factors affecting the adoption of different AFI. Given that a specific AFI adoption encompasses a complex process of development, adaptation, dissemination and adoption, it can be ruled that these studies provided a limited scope of the activities, actors and processes that involved in the process of technological change. The lack of investigation of a specific AF innovation from different perspectives (the innovation, household contexts and system level features) both on individual or combination of studies extends the limitations on partial discovery of the factors affecting AF adoption. Below, we further explore the relative importance of the factors from econometric models and show how recent studies largely exhibit the on-going inadequate understanding of the adoption problem in Africa.

### 3.2.3. Meta-analysis

The results of the meta-analysis showed that inclusion of the variables was often context specific and occasionally influenced by the research design. The studies employed on average 9.74 variables with a minimum of 2 and maximum of 20 variables in each econometric model. Thirteen, 42, 38 and 3 of the models employed a maximum of 5, 10, 15 and 20 variables in their models, respectively. Overall, the analysis illustrated that 45 out of 73 categorized variables were commonly used (>2 times) in the econometric models (Appendix A). Besides, the meta-analysis confirmed the prevalence of inconsistent relationship between variables and AF adoption decision. For example, the most highly computed age variable was positively (17), negatively (12) correlated and unassociated (57) to AF adoption decision. All variables computed 3 or times in econometric models experience such relationship to AF adoption except training related to AF (Appendix A). While the synthesis provides a general direction, it also illustrates the importance of recognizing the idiosyncrasies of specific AFI during studies and interventions. The intention of this meta-analysis was not to identify the effect of various variables rather to display the continuing shortcoming of past AF adoption research and propose a new way forward.

Correspondingly, there exist large differences with regard to the relative importance and frequency of use for category of variables as shown by the chord diagram (Figure 2) (Gu et al. 2014). Despite their frequent inclusion, demography and resource related variables did only show a strong association with the adoption decision in 32.17% and 36.53% of the reviewed studies illustrating their context-specific nature. In contrast, the less frequently investigated biophysical, behavioral, and market-related variables showed a significant association with AF adoption in 54.55%, 52.08% and 50% of cases; and social capital, livelihoods and institutions in 39.62%, 40.00% and 36.67% of cases.

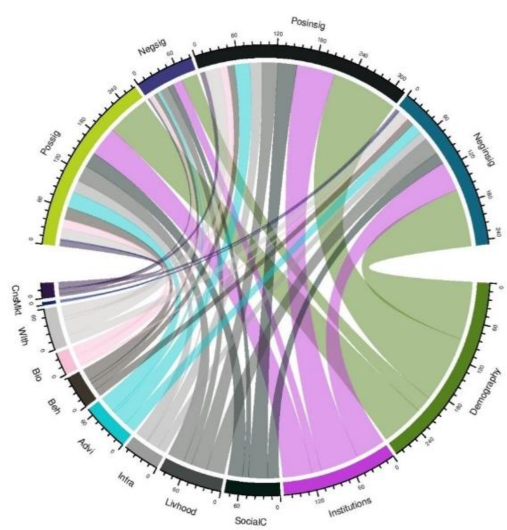


Figure 2. Significance size and direction of categorical variables (Definition of abbreviations; Possig=positively significant, Negsig=negatively significant, Posinsig= positively insignificant, Neginsig=negatively insignificant, Cns=constraints, Mkt=market, Bio=biophysical, Beh=behavioral/psychological, Advi=advisory/extension services, Infra=infrastructure, Livhood=livelihood, SocialC=social capital)

The comparative focus for models still leans to household contexts and system level features. The models employed and found +269|+321|-91|-251 positively significant, positively insignificant, negatively significant and negatively insignificant variables belonging to household contexts. The system level features comprise +177|+195|-61|-147 positively significant, positively insignificant, negatively significant and negatively insignificant variables, respectively. However, there is scarcity of variables related to innovation characteristics as illustrated by only 2 positively significant observability related variables.

In comparison to qualitative studies, econometric models provided insight into which variables influenced AF adoption in a way that is generalizable to a wider context (Appendix A). Proper measurement and inclusion of biophysical, behavioral and market-related factors as manifested in Fig. 2 become a good scientific practice while investigating the factors affecting adoption of AFI. Conversely, qualitative studies provided a wide range of knowledge and information including how reorganizing input supply systems, considering household decision making pattern and gender, assessing current state of policy frameworks, facilitating farmers experimentation and collaboration led to better adoption decisions. The depth of discussion embraced in most of these qualitative studies complements the narrow insights from econometric models.

### 3.2.4. Notable advances in adoption research

Notable recent findings from the broader agricultural sector argue long held facts on the relationship between different factors and innovation adoption. For example, Danquah and Joseph (2017) showed that education in SSA positively impacts adoption however has no effect on modification of these innovations. Without the ability to modify, innovations become static objects with a higher possibility of non-adoption or abandonment. Similarly, Fisher and Kandiwa (2014) confirmed the importance of power distribution (power index) at the household level on making adoption decision instead of gender of the household head alone. Fine scale findings continue to question the fidelity of earlier conclusions.

For example, general adoption literature substantiates the importance of social capital and networks for improving adoption through efficient information flows, access to inputs and credit (Fischer and Qaim 2012). However, Khataza et al.(2018) proved that different kinds of social capital have different impacts on adoption, away from the linear thinking. So, earlier research conclusions that education, gender and social capital are associated, whether negatively or positively, to AF adoption are crude configurations of how these variables are associated to AF adoption decision. Certainly, in addition to exploring new scopes of innovation adoption influencing factors, it is paramount importance to go beyond slim configurations and make explicit examination of existing relationships between adoption decision and factors of adoption for a more elaborate and concrete understanding of this association.

In regards to promotion approaches, in contrary to established notion of targeting few farmers Kebede and Zizzo (2015) suggested that promotion of innovations should target the majority of the community members at early stages of adoption rather than few innovators. Besides, the common public extension service primarily created knowledge and helped trial and adoption at early stages (Lambrecht et al. 2014) and required training to foster sustained adoption (Birhanu et al. 2017). Further, typical efforts of intensifying extension service at a particular site did not increase rate of adoption (Lambrecht et al. 2014) while pluralistic extension served the various households by creating range of actors to engage in dissemination roles (Martini et al. 2017). Pamuk et al. (2014) proved that the use of the recently familiar innovation platforms do not affect AFI adoption while robustly promoted crop innovations across various social groups. Similarly, previous studies executed possession of communication assets through information access to adoption of innovations; however, Abebe et al.(2013) proved that without designed ways of utilization, communication assets such as mobile phones are useless for innovation dissemination.

On the other hand , findings from the general agriculture corroborate that rate of adoption is generally related to the process of learning, innovation characteristics and features of adopting households (Pannell et al. 2006), not simple delivery of an innovation. Such process lends assimilation and information integration on products and processes and creates also the opportunity to operationalize household diversity (Micheels and Nolan 2016). Hence, along with strengthening farmer experimentation, redesigning institutions and policies relating to market structure, investments in education and training were found vital for the diffusion of innovations (Lybbert and Sumner 2012). Overall, due to the desire of prompting speed and course of innovation adoption, academicians (Hekkert et al. 2007; Glover et al. 2016) have provided extensive propositions on how adoption studies should be conducted in response to the adoption problem in SSA. Basically, Hekkert et al. (2007) emphasized the need to understand and map all the activities taking place within the change along existing and newly emerging innovations. Such action leads to examination of the activities important to develop, implement and disseminate different innovations (Hekkert et al. 2007). Likewise, Glover et al. (2016) argued that the current adoption concept (i.e., as static object) is flawed and misleads to inaccurate conclusions. The concept employed is spatially and temporally linear and hence shrouded as it ignores many important aspects of technological change and focused mainly on individual decisions.

Correspondingly, Hermans et al. (2013) proposed understanding how new innovations are developed and spread and how these processes are organized as an improvement to better comprehend and expedite innovation adoption. Studies should conceptualize adoption of innovations as a fluid assembly of social and technical components (Glover et al. 2016). As a result, Hekkert et al. (2007) provided set of activities, termed as functions of innovation systems, which are important to gain an insight into the processes that explain how well the innovation system is performing. These activities communicate adoption by comprehending the process of change, its complexity, levels and scales of operation and draw narratives relating to the innovation (Glover et al. 2016). A systems perspective had thus become increasingly popular (Hermans et al. 2013; Borremans et al. 2018). It offers the opportunity of linking aggregate diffusion process with micro-adoption and establishes firm understanding of diffusion patterns (Feder and Umali 1993). Following, we discuss the limitations of the different findings, develop a systems based analytical framework and provide concrete recommendations to foster AF innovations adoption.

## 4. DISCUSSION

### 4.1. Positive critique

From the seminal work on the adoption of agricultural innovations by Rogers (1983, 2003) to more recent contributions (Pattanayak et al. 2003; Mercer 2004), the understanding of the adoption process has constantly evolved; and the crave for greater understanding still exists. Latest propositions (Glover et al. 2016; Hekkert et al. 2007) further consolidated the need to provide strong lessons on how to better understand the adoption problem in SSA and consequently craft authentic suggestions for extensive adoption. A revisit of recent adoption studies in AF, however, largely confirmed the persistence of “reinventing the wheel” for undertaking adoption research limiting their contribution to robust policy and intervention actions. While there are several issues to discuss, 3 perspectives in criticizing the contribution of AF adoption studies emerged from our review; namely, view of adoption concept, data output and methodological defaults.

The appraisal of the review of literature indicates that a diversity of variables influenced the adoption of AFI, which cannot be appropriately captured through analyses that focus on single aspects. Due to the narrow focus on understanding the elements, mechanisms and principles of adoption, most recent adoption studies failed to provide concrete responses to earlier calls of detailed explanation of the issues central for making AF adoption decisions. Mercer and Miller (1998) indicate the inadequate inclusion of many basic and distinguishing features of AF, such as multiple input and output nature, in socioeconomic modeling efforts. The studies principally placed their focus/unit of analysis at household level and neglected the process of innovation development, diffusion and adoption. Adoption of innovations could, however, be fairly understood by understanding patterns of diffusion (i.e., changes in the process) and the structure (i.e., how different actors interact) and decision-making process that influenced innovation adoption (Hermans et al. 2013). The economic roles of AF innovations and their impact on livelihoods as well as temporal and spatial variability of AF are less explored to date (Mercer and Miller 1998).

Analytical and theoretical focus is needed on how farmers value the different land use attributes and the trade-offs involved in AF systems (Mercer and Miller 1998). Looking into the AF adoption studies (GYAU et al. 2012), the review found no evidence of the inclusion of the multiple input-output nature of AF innovations as well as the conceptualization of adoption as a process; rather adoption was considered as static event, universally by the use of mainly binary models and standalone explanations. Further, the studies provided fair information on a diversity factors affecting AF innovation adoption; however, they lagged behind recent advances in frameworks of analysis by pursuing common approaches and putting forth almost similar advocacies. Dependency on narrow knowledge base in analysis and absence of systems perspectives persisted across the studies.

Despite significant efforts in research and publishing, most of the recent adoption literature has made relatively modest contributions to advancement of knowledge on AF adoption as nearly all of these studies seemed to repeat conventional study designs in new geographical conditions and landscapes. Limited numbers of similar variables are often inserted in a presumably biased attitude to establish significant output. The frequently explored variables and where 'robust relationship' was established were limited to only specific categories (Figure 2), mainly socioeconomic and much of the issues identified in recent general adoption studies were not incorporated. Particular progress made comprised the efforts in including socio-psychological conditions (e.g. perceived behavioral control), perception of tree non-monetary benefits (e.g., as hosts of biological control methods), farmers' involvement in field experimentation and more elaborate social capital characters and networking (e.g., ties with neighbors and other stakeholders; bridging and bonding) as well as scant references on policy interventions. As a result, AF adoption studies (Appendix A) essentially provided verification to earlier findings (i.e., fragmented information) and added very little in new knowledge how AF innovations are adopted.

In the 96 econometric models, 59.14 % treated AF adoption as a binary outcome of adopt and not adopt (Figure 1). Discrete choice nature of the dependent variables was however notified as a limitation to studies for policy recommendations (Pattanayak et al. 2003). Variables specification and study design problems were observed due to haphazard employment of models without accounting the probability distribution assumptions. Few of the models (10.75%) had serious methodological shortcomings in model design by employing linear regression and binary models while the binomial distribution (and its subsequent Poisson regression and its family) was econometrically the recommended method. In 20.69% of the studies, the selection of variables was not based on the qualitative and descriptive statistics findings nor on theoretical foundations rather followed 'kitchen sink approach'. Further, 10.34% of the econometrics based studies showed significant discrepancies to contemporary understandings by considering (male) adult family members as the only contributors in the AF practice which was an ignorance of the contribution of women farmers and children in the overall agricultural production in SSA.

Methodological default and limited vigor was common among the studies while exploring the factors affecting AF adoption decision process at the household level. Thorough profitability analysis remained mostly unanswered (Pattanayak et al. 2003), except an instance by Rahim et al. (2007). The existence of limitations in both the financial analysis and reporting of forestry investments was acknowledged (Harrison and Herbohn 2016). Besides, the reviewed studies mostly relied on employing simple proxy variables (e.g., tenure secured and unsecured) on analyzing risk and uncertainty, a critical variable for AF adoption (Molua 2005), further limiting the accuracy and validity of the results.

The numerous adoption studies conducted so far have revealed a large number of different factors that contributed to adoption in one way or another. Yet, as also shown by the large proportion of inconclusive, insignificant or contradictory relationships for one and the same variable in various studies, most of these relationships were context-specific and can hardly be generalized. Further insight cannot be expected from continuing the same type of research over and over again (Hoffman 2007). What really needed is to evaluate the effect of these various factors during the adoption process (i.e., their sequence, duration, intermittence etc.).

### 4.2. Outlook

The reviewed studies investigated a diversity of issues affecting AF adoption ranging from gender (Elias 2015), policy frameworks (Foundjem-Tita et al. 2013), profitability (Duguma 2013) to general output analysis of a project and household contexts and system level features solely and in combination with biophysical information (Ajayi et al. 2011b; Bucagu et al. 2013). However, our point of departure comes from the understanding that all these studies present a fragment of the factors and contexts that affect AF innovation adoption. A systems perspective is thus imperative in order to achieve the desired comprehension for low uptake of AF innovations in SSA.

Identically, despite appreciation of his contributions, Rogers (2003) was criticized for (over-) simplifying the complex adoption-diffusion process (Hoffman 2007). He showcased few principles and limited number of generalizations out of the numerous, complex and diverse reality of innovation adoption domains. Similarly, the contributions of recent AF adoption studies is marginal as almost all have universally understood and examined AF adoption as a detached decision point unrelated with other decision making contexts of households and organizations.

Critical emphasis is thus indispensable on conceptualizing adoption and on improving the analytical approach of conducting AF adoption research.

**Visioning adoption-diffusion from a systems concept**

Recent developments in propositions (Glover et al. 2016; Hekkert et al. 2007) confirmed that adoption of innovations should be viewed as a result of integrated sub-systems (Figure 3). Similarly, AF innovation adoption, as indicated by fragmented findings of the reviewed studies, is influenced by a host of innovation characteristics, household contexts and system level features. Glover et al. (2016) argued that innovation should be conceived as fluid assembly of both social and technical components that people do, make or remake, not something they received or adopted. They further underline the need to deal with the spatial and temporal dynamic process of adoption such as whether an innovation was tried for one season in a small size, used for a few years and then abandoned or used on an ongoing basis. Altogether, mechanisms that facilitated systematic, holistic assessment of the spread and consequential impact of potential interventions lend a greater understanding of all processes and interactions at different scales and increase the quality of models and robustness of assessments (Notenbaert et al. 2017).

Further, Hekkert et al (2007) proposed and demonstrated an elaborative way of understanding the process of technological change. The proposition is embraced by this article due to its leniency to a holistic approach of dealing with adoption. Termed as 'functions of innovation systems', it comprises 7 core elements that can be elucidated by process/historical analysis; namely, entrepreneurial activity, knowledge development, knowledge diffusion, guidance of the search, market formation, resources mobilization and creation of legitimacy.

By further incorporating the largely excluded household contexts, a new analytical framework (Figure 3) is developed. It comprises the different functions of innovation systems under 3 interlinked but compartmentalized elements of the innovation system. The first element is the innovation itself which comprises the characteristics and the source of the innovation (Rogers 2003). Individual entrepreneurs, farm households, research institutes, agricultural offices, or NGOs could be sources of the innovation. Innovations that fit farmers long established practices, those ensuring food security or that minimize risk or that fit a specific purpose (Meijer et al. 2015b) lead to adoption through the medium of communication or policy actions or markets. Market facilitation through marketing instruments and policy regulations on new product development and movement (Hekkert et al. 2007) become central at the diffusion stage of the innovation. The second element, system level features facilitates the conditions for adoption through modification/adaptation of the innovation package through concerted research-extension and development efforts. The proper and smooth interaction and networking among the system level features is as essential as the farmers for adoption and diffusion of innovations.

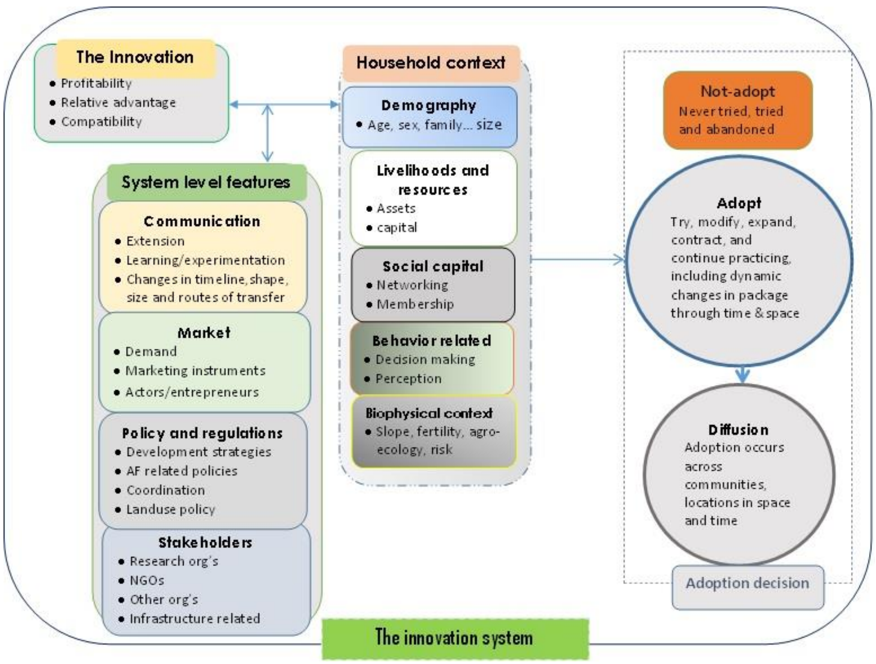


Figure 3. AFI adoption analytical framework (source: own elaborated adapted from reviewed literature)

The existence and proper functioning, coordination and collaboration of different organizations and institutions form the basis of system level features. Such organizations as research institutes serve as primary sources of innovations, ministries and bureaus of agriculture and environment support the mobilization of resources for research and extension while at the same time providing and organizing the delivery, experimentation and promotion of the innovations. NGOs play supporting roles in promotion through skills development, creating platforms for training and local collaboration among families and communities. Based on the specific innovation, various organizations involve at different stages of the innovation development, trial or experimentation, promotion and diffusion (Lillesø et al. 2011).

The 3rd element consists of the farm household contexts where the final adoption-decision is made based on resources, priority, and innovation characteristics (Meijer et al. 2015b). The decision either leads to non-adoption at all, adoption at innovators levels or may diffuse across communities otherwise may result in abandonment. These decisions have implications for the farm households and system level actors through resource allocation, market creation, or creation of new regulations that favor the proper functioning of the new innovation which creates a new innovation system embedded on the existing system (Hekkert et al. 2007). Beyond adoption, farmers can also serve as innovation sources (i.e., through experimentation) and disseminators.

The feedbacks from adoption during trial or experimentation may result in change of the original innovation package (e.g., management intensity) and these feedbacks may be either given as input to the system level features for consideration for future diffusion interventions or the innovation characteristics may be directly changed to suit local demands and context. Innovations can also diffuse without much intervention with the system level features in cases where, the innovation characteristics fulfilled the specific needs and priorities of large group of farm households. Among all variables and actors, risk and uncertainty happens to occur at all levels including at innovation attributes (e.g., incompatible innovation), household contexts (such as production risk, e.g., weather patterns, diseases; household related such as labor or health) and system level features (such as policy risks, i.e. changes in government policy; market risk e.g., reduced demand).

Mapping how components of the 3 elements within the innovation system interact, developing the feedback loop and configuring hotspots or principal components of the innovation system is essential to better understand how AFI are developed, modified, disseminated and sustainably adopted. Also, mapping assists to better recognize the key activities for abandonment or change in scale of adoption. There are cases where feedbacks are not collected for improvement especially in non-adopted innovations and this is one of the core areas for improving the innovation system by looking deep into the process of innovation development, transfer, change, interaction and adoption. Overall, during and after adoption, the innovation creates disturbance to the existing innovation system creating new or improved contexts in which system level features favor AF adoption. Otherwise, if it is embedded only on the existing innovation system or is met by another new innovation providing greater benefits and compatibility, could lead to large scale dis-adoption or abandonment.

**Improving analysis:** methodologically, multiple methods and data should be used to gain a fair understanding of the multidimensional AF adoption process. Qualitative/ethnographic studies should seek to explore and map the interaction among different activities in addition to the common content analysis and descriptive statistics. Such investigations make scientific findings, instead of development actor intuitions, foundations of AF development interventions (Partey et al. 2017). With regard to quantitative research, studies should provide insight on the decision making process away from single decision making points (i.e. by cuddling size and time of adoption vs. non-adoption as binary dependent variable). AF adoption analysis, therefore, must elucidate the different stages of adoption, time lags in adoption, intensity of adoption, management and dis-adoption. Also, fine scale investigation of some of the variables (e.g., household level power index, social capital) provides additional information towards AF adoption decision making. With respect to econometric model selection, fine-tuning is required on strictly following the basic assumptions on the model selection verses the dependent variable employed (e.g., count outcome models are more meaningful than linear regression models for data like number of tree species adopted as a dependent variable).

Throughout the years' research on thorough profitability analysis and the role of risk and uncertainty had been called for but there were scarce studies addressing these issues. While we call for further studies in this regard, we also suggest that profitability analysis should be more vigorous by incorporating such factors as multiple input-output nature, time and intensity of AF adoption. Real Options Approach, rather than the common discount methods (e.g., net present value), is reasonably a better analysis technique as it takes uncertainty and AF adoption flexibility into account (Krychowski and Quélin 2010; Rahim et al. 2007).

**Improving AF interventions:** with regard to extension, employing alternative extension methods amid the limited effect of advisory services is vital during interventions. The prevalence of inconsistent relationship between variables and AF adoption as well as the difference among farmers on opportunity seeking behavior and resources demands the disaggregation and localization of interventions instead of following one size fits all strategy.

The commonly available advisory service to smallholder farmers, public extension, only played the role of knowledge creation as documented by agricultural innovation adoption studies. So, in the attempt for broad AF adoption, extension services should be accompanied by further trainings and demonstrations. Moreover, use of existing social capitals and employing pluralistic extension methods is vital for better development outputs. Employing innovation platforms as alternative extension methods, whose effect on AF adoption remains least understood, presents an opportunity to reach the target farmers for extensive adoption. Other issues such as encouragement of farmer experimentation, creation of partnership with relevant stakeholders, designing appropriate ways to utilize information communication assets (e.g., mobile phones), and shunning off doing extension service (for example, demonstration) over and over again in one place are fundamental for effective extension intervention.

## 5. CONCLUSION AND IMPLICATIONS

The review provided useful insight into the state of AF adoption studies and the revisit indicated that (i) the volume of research in this area was limited given the number of nations and the years, (ii) the studies mainly followed the common adoption study techniques known in crop and livestock technologies, and (iii) adoption studies in AF were not based on systems thinking rather in piecemeal approach resulting in fractional discovery of factors affecting AF adoption. From the review decent lessons can be produced for improving the existing extension system, improving studies and further investigation of factors whose relationship is not firmly established for better comprehension of the AF innovation-adoption-diffusion process.

Chronological evaluation of previous studies leads to the conclusion that most of the calls of AF adoption studies as recommended by the reviewers left unanswered by proceeding authors who did research in AF adoption. Issues such as multiple input-output, inter temporal nature and multiple economic roles of trees on farms were less explored. Robust analysis is expected on the role of risk and profitability on adoption of AFI. Again the role of different extension methods (e.g., group methods) and non-market valuation need to be investigated. Overall, studies should explore loop holes for improvement or success of a new innovation system across communities, locations, time and contexts.

Expanding our understanding of the adoption issue requires looking both at fine details (e.g., between bridging and bonding social capital) and visualizing adoption in the helms of innovation systems (holistic approach) and the associated dynamism. The mere dependence on mechanical and statistical significance is detrimental to critical thinking while at the same time traditional analysis techniques continue to contribute to broaden our understanding of AF adoption. As a result, qualitative description of the flow of the innovation must be part of the analysis by conceiving adoption as a product of a system of integrated activities with 3 broadly classified categories; namely, the innovation itself, household contexts and system level features. By recommending systems approach, we are not at all discouraging individual analysis rather suggesting it as a higher level enquiry to properly understand the whole context of technological change. Several individual studies, on a particular innovation, can also provide an amalgamated result that fully illuminates the adoption process starting from technology development to ultimate adoption.

Improving the current extension can be profoundly made possible by incorporating long established relationships among variables and adoption as well as incorporation of recent findings. Recognizing such things as differences in resource endowments and environmental context as well as target population heterogeneity (e.g., disaggregation and stratification) as manifested by non-consistency of factors to adoption of AFI is essential for successful extension interventions. Also, proper utilization of communication assets such as mobile phones (e.g., for dissemination of specific innovations) is key for effective promotion of AFI.

On scrutinizing not firmly established relationships at least few factors need further contextual analysis. The conclusion that likelihood of adoption rate was not increased by intensifying extension interventions at a particular site and target group should be verified by a cross sectional data as if true minimizes cost and ensures equity among communities on using public resources. Also, with meagre information, studies on innovation platforms, sabotaging behavior of farmers, household level power index and the impacts of human capital on innovation and adoption of AFI will clear the doubt and guide future interventions.

**Supplementary files:** Appendix A

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Publication bibliography

Abebe, Gumataw K.; Bijman, Jos; Pascucci, Stefano; Omta, Onno (2013): Adoption of improved potato varieties in Ethiopia: The role of agricultural knowledge and innovation system and smallholder farmers' quality assessment. In *Agricultural Systems* 122, pp. 22–32. DOI: 10.1016/j.agsy.2013.07.008.

Abiyu, Abrham; Teketay, Demel; Gratzer, Georg; Shete, Maru (2016): Tree Planting by Smallholder Farmers in the Upper Catchment of Lake Tana Watershed, Northwest Ethiopia. In *Small-scale Forestry* 15 (2), pp. 199–212. DOI: 10.1007/s11842-015-9317-7.

Ajayi, Oluyede Clifford; Place, Frank; Akinnifesi, Festus Kehinde; Sileshi, Gudeta Weldsesemayat (2011a): Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). In *International Journal of Agricultural Sustainability* 9 (1), pp. 129–136. DOI: 10.3763/ijas.2010.0554.

Ajayi, Oluyede Clifford; Place, Frank; Akinnifesi, Festus Kehinde; Sileshi, Gudeta Weldsesemayat (2011b): Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). In *International Journal of Agricultural Sustainability* 9 (1), pp. 129–136. Available online at DOI: 10.3763/ijas.2010.0554.

Amare, Dagninet; Wondie, Menale; Mekuria, Wolde; Darr, Dietrich (2019): Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. In *Small-scale Forestry* 18 (1), pp. 39–56. Available online at DOI: 10.1007/s11842-018-9405-6.

Appiah, Mark; Pappinen, Ari (2010): Farm Forestry Prospects Among Some Local Communities in Rachuonyo District, Kenya. In *Small-scale Forestry* 9, pp. 297–316. DOI: 10.1007/s11842-010-9117-z.

Bachewe, Fantu N.; Berhane, Guush; Minten, Bart; Taffesse, Alemayehu S. (2018): Agricultural Transformation in Africa? Assessing the Evidence in Ethiopia. In *World Development* 105, pp. 286–298. DOI: 10.1016/j.worlddev.2017.05.041.

Birhanu, Mulugeta Yitayih; Girma, Anteneh; Puskur, Ranjitha (2017): Determinants of success and intensity of livestock feed technologies use in Ethiopia: Evidence from a positive deviance perspective. In *Technological Forecasting and Social Change* 115, pp. 15–25. DOI: 10.1016/j.techfore.2016.09.010.

Borremans, L.; Marchand, F.; Visser, M.; Wauters, E. (2018): Nurturing agroforestry systems in Flanders: Analysis from an agricultural innovation systems perspective. In *Agricultural Systems* 162, pp. 205–219. Available online at DOI: 10.1016/j.agsy.2018.01.004.

Bucagu, C.; Vanlauwe, B.; van Wijk, M. T.; Giller, K. E. (2013): Assessing farmers' interest in agroforestry in two contrasting agro-ecological zones of Rwanda. In *Agroforest Syst* 87 (1), pp. 141–158. DOI: 10.1007/s10457-012-9531-7.

Chukwuone, N. A. (2009): Socioeconomic determinants of cultivation of non-wood forest products in southern Nigeria. In *Biodivers Conserv* 18 (2), pp. 339–353. DOI: 10.1007/s10531-008-9489-y.

Conteh, Alhaji M. H.; Moiwo, Juana P.; Yan, Xiangbin (2016): Using a Logistic Regression Model to Analyze Alley Farming Adoption Factors in Sierra Leone. In *Small-scale Forestry* 15 (1), pp. 109–125. Available online at DOI: 10.1007/s11842-015-9311-0.

Danquah, Michael; Joseph, Amankwah-Amoah (2017): Assessing the relationships between human capital, innovation and technology adoption: Evidence from sub-Saharan Africa. In *Technological Forecasting and Social Change* 122, pp. 24–33. Available online at DOI: 10.1016/j.techfore.2017.04.021.

Dawson, Neil; Martin, Adrian; Sikor, Thomas (2016): Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. In *World Development* 78, pp. 204–218. Available online at DOI: 10.1016/j.worlddev.2015.10.008.

Duguma, Lalisa Alemayehu (2013): Financial analysis of agroforestry land uses and its implications for smallholder farmers livelihood improvement in Ethiopia. In *Agroforest Syst* 87 (1), pp. 217–231. DOI: 10.1007/s10457-012-9537-1.

Elias, Marlene (2015): Gender, knowledge-sharing and management of shea (Vitellaria paradoxa) parklands in central-west Burkina Faso. In *Journal of Rural Studies* 38, pp. 27–38.

Fahmi, Mustafa Kamil Mahmoud; Mohamed, Elamin Sanjak; Kanninen, Markku; Luukkanen, Olavi; Kalame, Fobissie Blese; Eltayeb, Abdalla Mirghani (2015): Determinants and constraints of integrating natural acacias into mechanised rain-fed agricultural schemes Sennar State, Sudan. In *GeoJournal* 80 (4), pp. 555–567. DOI: 10.1007/s10708-014-9563-9.

Feder, Gershon; Just, Richard E.; Zilberman, David (1985): Adoption of Agricultural Innovations in Developing Countries: A Survey. In *Economic Development and Cultural Change* 33 (2), pp. 255–298. Available online at DOI: 10.1086/451461.

Feder, Gershon; Umali, Dina L. (1993): The adoption of agricultural innovations. In *Technological Forecasting and Social Change* 43 (3–4), pp. 215–239. Available online at DOI: 10.1016/0040-1625(93)90053-A.

Fischer, Elisabeth; Qaim, Matin (2012): Linking Smallholders to Markets: Determinants and Impacts of Farmer Collective Action in Kenya. In *World Development* 40 (6), pp. 1255–1268. DOI: 10.1016/j.worlddev.2011.11.018.

Fisher, Monica; Kandiwa, Vongai (2014): Can agricultural input subsidies reduce the gender gap in modern maize adoption? Evidence from Malawi. In *Food Policy* 45, pp. 101–111. DOI: 10.1016/j.foodpol.2014.01.007.

Foundjem-Tita, Divine; Tchoundjeu, Zac; Speelman, Stijn; D'Haese, Marijke; Degrande, Ann; Asaah, Ebenezer et al. (2013): Policy and Legal Frameworks Governing Trees: Incentives or Disincentives for

Smallholder Tree Planting Decisions in Cameroon? In *Small-scale Forestry* 12 (3), pp. 489–505. DOI: 10.1007/s11842-012-9225-z.

Gibreel, Tarig M. (2013): Crop commercialization and adoption of gum-arabic agroforestry and their effect on farming system in western Sudan. In *Agroforest Syst* 87 (2), pp. 311–318. DOI: 10.1007/s10457-012-9552-2.

Glover, Dominic; Sumberg, James; Andersson, Jens A. (2016): The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. In *Outlook Agric* 45 (1), pp. 3–6. Available online at DOI: 10.5367/oa.2016.0235.

Gu, Zuguang; Gu, Lei; Eils, Roland; Schlesner, Matthias; Brors, Benedikt (2014): circlize Implements and enhances circular visualization in R. In *Bioinformatics (Oxford, England)* 30 (19), pp. 2811–2812. DOI: 10.1093/bioinformatics/btu393.

GYAU, A.; CHIATOH, M.; Franzel, S.; ASAAH, E.; DONOVAN, J. (2012): Determinants of farmers' tree planting behavior in the north west region of Cameroon: the case of Prunus africana. In *International Forestry Review* 14 (3), pp. 265–274.

Haile, Getahun; Lemenih, Mulugeta; Senbeta, Feyera; Itanna, Fisseha (2017): Plant diversity and determinant factors across smallholder agricultural management units in Central Ethiopia. In *Agroforest Syst* 91 (4), pp. 677–695. DOI: 10.1007/s10457-016-0038-5.

Harrison, Steve; Herbohn, John (2016): Financial Evaluation of Forestry Investments: Common Pitfalls and Guidelines for Better Analyses. In *Small-scale Forestry* 15 (4), pp. 463–479. Available online at DOI: 10.1007/s11842-016-9334-1.

Hekkert, M. P.; Suurs, R.A.A.; Negro, S. O.; Kuhlmann, S.; Smits, R.E.H.M. (2007): Functions of innovation systems: A new approach for analysing technological change. In *Technological Forecasting and Social Change* 74 (4), 413–432. Available online at DOI: 10.1016/j.techfore.2006.03.002.

Hermans, Frans; Stuiver, Marian; Beers, P. J.; Kok, Kasper (2013): The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. In *Agricultural Systems* 115, pp. 117–128. Available online at DOI: 10.1016/j.agsy.2012.09.006.

Hoffman, Voker (2007): Five editions (1962-2003) of Everett Rogers's Diffusion of Innovations: Book Review. In *The Journal of Agricultural Education and Extension* 13 (2), pp. 147–158. Available online at DOI: 10.1080/13892240701289601.

IHEKE, Onwuchekwa Raphael; AGODIKE, Winner Chiagoziem (2006): ANALYSIS OF FACTORS INFLUENCING THE ADOPTION OF CLIMATE CHANGE MITIGATING MEASURES BY SMALLHOLDER FARMERS IN IMO STATE, NIGERIA. In *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development* 16 (1), pp. 213–220.

Iiyama, Miyuki; Derero, Abayneh; Kelemu, Kaleb; Muthuri, Catherine; Kinuthia, Ruth; Ayenkulu, Ermias et al. (2017): Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. In *Agroforest Syst* 91 (2), pp. 271–293. DOI: 10.1007/s10457-016-9926-y.

Isaac, Marney E.; Erickson, Bonnie H.; Quashie-Sam, S. James; Timmer, Vic R. (2007): Transfer of Knowledge on Agroforestry Management Practices: the Structure of Farmer Advice Networks. In *Ecology* *and society* 12 (2). Available online at Available online at http://www.ecologyandsociety.org/vol12/iss2/art32/.

Ite, Uwem E. (2005): Tree integration in homestead farms in southeast Nigeria: propositions and evidence. In *The Geographical Journal* 171 (3), pp. 209–222. Available online at Available online at https://rgs-ibg.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1475-4959.2005.00161.x.

Jerneck, Anne; Olsson, Lennart (2013): More than trees! Understanding the agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya. In *Rural Studies* 32, pp. 114–125. Available online at DOI: 10.1016/j.jrurstud.2013.04.004.

Johansson, Karl-Erik; Axelsson, Robert; Kimanzu, Ngolia; Sassi, Samuel; Bwana, Eliza; Otsyina, Robert (2013): The Pattern and Process of Adoption and Scaling up: Variation in Project Outcome Reveals the Importance of Multilevel Collaboration in Agroforestry Development. In *Sustainability* 5 (12), pp. 5195–5224. DOI: 10.3390/su5125195.

Kebede, Bereket; Zizzo, Daniel John (2015): Social Preferences and Agricultural Innovation: An Experimental Case Study from Ethiopia. In *World Development* 67, pp. 267–280. DOI: 10.1016/j.worlddev.2014.10.022.

Khataza, Robertson R.B.; Doole, Graeme J.; Kragt, Marit E.; Hailu, Atakelty (2018): Information acquisition, learning and the adoption of conservation agriculture in Malawi: A discrete-time duration analysis. In *Technological Forecasting and Social Change* 132, pp. 299–307. DOI: 10.1016/j.techfore.2018.02.015.

Kiptot, Evelyne (2008): ADOPTION DYNAMICS OF TITHONIA DIVERSIFOLIA FOR SOIL FERTILITY MANAGEMENT IN PILOT VILLAGES OF WESTERN KENYA. In *Ex. Agric.* 44 (4), pp. 473–484. DOI: 10.1017/S0014479708006704.

Kiptot, Evelyne; Franzel, Steven; Hebinck, Paul; Richards, Paul (2006): Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. In *Agroforest Syst* 68 (3), pp. 167–179. DOI: 10.1007/s10457-006-9007-8.

Kiptot, Evelyne; Hebinck, Paul; Franzel, Steven; Richards, Paul (2007a): Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. In *Agricultural Systems* 94 (2), pp. 509–519. Available online at DOI: 10.1016/j.agsy.2007.01.002.

Kiptot, Evelyne; Hebinck, Paul; Franzel, Steven; Richards, Paul (2007b): Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. In *Agricultural Systems* 94 (2), pp. 509–519. DOI: 10.1016/j.agsy.2007.01.002.

Krychowski, Charlotte; Quélin, Bertrand V. (2010): Real Options and Strategic Investment Decisions: Can They Be of Use to Scholars? In *Academy of Management Perspectives* 24 (2), pp. 65–78. DOI: 10.5465/AMP.2010.51827776.

Lambrecht, Isabel; Vanlauwe, Bernard; Merckx, Roel; Maertens, Miet (2014): Understanding the Process of Agricultural Technology Adoption: Mineral Fertilizer in Eastern DR Congo. In *World Development* 59, pp. 132–146. Available online at DOI: 10.1016/j.worlddev.2014.01.024.

Lillesø, J. B. L.; Graudal, L.; Moestrup, S.; Kjær, E. D.; Kindt, R.; Mbora, A. et al. (2011): Innovation in input supply systems in smallholder agroforestry: seed sources, supply chains and support systems. In *Agroforest Syst* 83 (3), pp. 347–359. DOI: 10.1007/s10457-011-9412-5.

Lybbert, Travis J.; Sumner, Daniel A. (2012): Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. In *Food Policy* 37 (1), pp. 114–123. DOI: 10.1016/j.foodpol.2011.11.001.

Marra, Michele; Pannell, David J.; Abadi Ghadim, Amir (2003): The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? In *Agricultural Systems* 75 (2-3), pp. 215–234. DOI: 10.1016/S0308-521X(02)00066-5.

Mbosso, Charlie; Degrande, Ann; Villamor, Grace B.; van Damme, Patrick; Tchoundjeu, Zac; Tsafack, Sygnola (2015): Factors affecting the adoption of agricultural innovation: the case of a Ricinodendron heudelotii kernel extraction machine in southern Cameroon. In *Agroforest Syst* 89 (5), pp. 799–811. DOI: 10.1007/s10457-015-9813-y.

Meijer, Seline S.; Catacutan, Delia; Ajayi, Oluyede C.; Sileshi, Gudeta W.; Nieuwenhuis, Maarten (2015b): The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. In *International Journal of Agricultural Sustainability* 13 (1), pp. 45–54. Available online at DOI: 10.1080/14735903.2014.912493.

Meijer, Seline S.; Catacutan, Delia; Sileshi, Gudeta W.; Nieuwenhuis, Maarten (2015a): Tree planting by smallholder farmers in Malawi: Using the theory of planned behavior to examine the relationship between attitudes and behavior. In *Journal of Environmental Psychology* 43, pp. 1–12. Available online at DOI: 10.1016/j.jenvp.2015.05.008.

Mercer, D. E. (2004): Adoption of agroforestry innovations in the tropics: A review. In *Agroforest Syst* 61-62 (1-3), pp. 311–328. Available online at DOI: 10.1023/B:AGFO.0000029007.85754.70.

Mercer, D. E.; Miller, R. P. (1998): Socioeconomic research in agroforestry:progress, prospects, priorities. In *Agroforestry Systems* 38, pp. 177–193.

Micheels, Eric T.; Nolan, James F. (2016): Examining the effects of absorptive capacity and social capital on the adoption of agricultural innovations: A Canadian Prairie case study. In *Agricultural Systems* 145, pp. 127–138. DOI: 10.1016/j.agsy.2016.03.010.

Molua, Ernest L. (2005): The economics of tropical agroforestry systems: the case of agroforestry farms in Cameroon. In *Forest Policy and Economics* 7 (2), pp. 199–211. DOI: 10.1016/S1389-9341(03)00032-7.

Montambault, Jensen Reitz; Alavalapati, Janaki R. R. (2005): Socioeconomic research in agroforestry: a decade in review. In *Agroforest Syst* 62 (2), pp. 151–161. Available online at DOI: 10.1007/s10457-005-0124-6.

Musa, Frank; Kamoto, Judith; Jumbe, Charles; Zulu, Leo (2018): Adoption and the Role of Fertilizer Trees and Shrubs as a Climate Smart Agriculture Practice: The Case of Salima District in Malawi. In *Environments* 5 (11), p. 122. DOI: 10.3390/environments5110122.

Mutsvangwa-Sammie, Eness P.; Manzungu, Emmanuel; Siziba, Shephard (2017): Profiles of innovators in a semi-arid smallholder agricultural environment in south west Zimbabwe. In *Physics and Chemistry of the Earth, Parts A/B/C* 100, pp. 325–335. DOI: 10.1016/j.pce.2016.09.002.

Nahayo, Alphonse; Pan, Genxing; Joseph, Stephen (2016): Factors influencing the adoption of soil conservation techniques in Northern Rwanda. In *J. Plant Nutr. Soil Sci.* 179 (3), pp. 367–375. DOI: 10.1002/jpln.201500403.

Ndayambaje, J. D.; Heijman, W. J. M.; Mohren, G. M. J. (2012): Household Determinants of Tree Planting on Farms in Rural Rwanda. In *Small-scale Forestry* 11 (4), pp. 477–508. DOI: 10.1007/s11842-012-9196-0.

Notenbaert, An; Pfeifer, Catherine; Silvestri, Silvia; Herrero, Mario (2017): Targeting, out-scaling and prioritising climate-smart interventions in agricultural systems: Lessons from applying a generic framework to the livestock sector in sub-Saharan Africa. In *Agricultural Systems* 151, pp. 153–162. DOI: 10.1016/j.agsy.2016.05.017.

Owombo, P. T.; Idumah, F. O. (2017): Determinants of agroforestry technology adoption among arable crop farmers in Ondo state, Nigeria: an empirical investigation. In *Agroforest Syst* 91 (5), pp. 919–926. DOI: 10.1007/s10457-016-9967-2.

Pamuk, Haki; Bulte, Erwin; Adekunle, Adewale A. (2014): Do decentralized innovation systems promote agricultural technology adoption? Experimental evidence from Africa. In *Food Policy* 44, pp. 227–236. DOI: 10.1016/j.foodpol.2013.09.015.

Pannell, D. J.; Marshall, G. R.; Barr, N.; Curtis, A.; Vanclay, F.; Wilkinson, R. (2006): Understanding and promoting adoption of conservation practices by rural landholders. In *Aust. J. Exp. Agric.* 46 (11), p. 1407. DOI: 10.1071/EA05037.

Partey, Samuel T.; Sarfo, Daniel A.; Frith, Oliver; Kwaku, Michael; Thevathasan, Naresh V. (2017): Potentials of Bamboo-Based Agroforestry for Sustainable Development in Sub-Saharan Africa: A Review. In *Agric Res* 6 (1), pp. 22–32. DOI: 10.1007/s40003-017-0244-z.

Pattanayak, Subhrendu K.; Evan Mercer, D.; Sills, Erin; Yang, Jui-Chen (2003): Taking stock of agroforestry adoption studies. In *Agroforest Syst* 57 (3), pp. 173–186. Available online at DOI: 10.1023/A:1024809108210.

Rahim, Afaf H.; van Ierland, Ekko C.; Wesseler, Justus (2007): Economic incentives for abandoning or expanding gum arabic production in Sudan. In *Forest Policy and Economics* 10 (1-2), pp. 36–47. Available online at DOI: 10.1016/j.forpol.2007.02.002.

Rogers, E. M. (1983): Diffusion of Innovations. 3rd. New York: The Free press.

Rogers, E. M. (2003): Diffusion of innovations. 5th. New York: Free Press.

Sanginga, Pascal C.; Kamugisha, Rick N.; Martin, Adrienne M. (2006): Conflicts management, social capital and adoption of agroforestry technologies: empirical findings from the highlands of southwestern Uganda. In *Agroforest Syst* 69 (1), pp. 67–76. DOI: 10.1007/s10457-006-9018-5.

Sirrine, Dorothy; Shennan, Carol; Snapp, Sieglinde; Kanyama-Phiri, George; Kamanga, Bernard; Sirrine, J. Robert (2010): Improving recommendations resulting from on-farm research: agroforestry, risk, profitability and vulnerability in southern Malawi. In *International Journal of Agricultural Sustainability* 8 (4), pp. 290–304. DOI: 10.3763/ijas.2010.0471.

Toth, Gregory G.; Ramachandran Nair, P. K.; Jacobson, Michael; Widyaningsih, Yekti; Duffy, Colm P. (2017): Malawi's Energy Needs and Agroforestry: Adoption Potential of Woodlots. In *Hum Ecol* 45 (6), pp. 735–746. DOI: 10.1007/s10745-017-9944-z.

Vanlauwe, B.; Coyne, D.; Gockowski, J.; Hauser, S.; Huising, J.; Masso, C. et al. (2014): Sustainable intensification and the African smallholder farmer. In *Current Opinion in Environmental Sustainability* 8, pp. 15–22. DOI: 10.1016/j.cosust.2014.06.001.

## 4.2. Can a sequential analysis provide a more robust understanding of farmers' adoption decisions? an example from an agroforestry adoption study in Ethiopia

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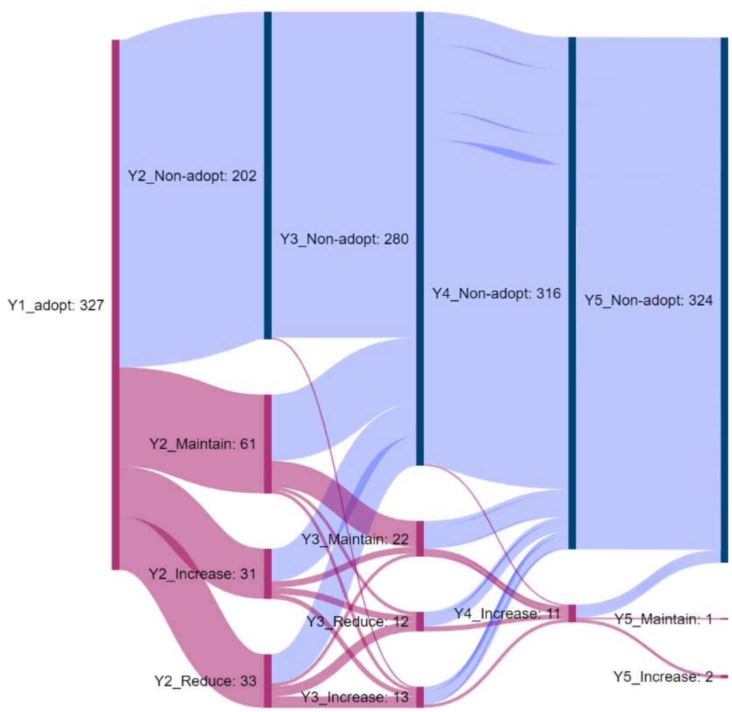
## GRAPHICAL ABSTRACT




Graph for combined adoption decision of farmers across seasons

## HIGHLIGHTS

- Retrospective inquiry coupled with content analysis provided better insights into the farmers' adoption behaviors
- Our analysis demonstrated alternating critical factors for making initial and follow-up adoptions
- Linking research tools or questions with extraordinary events facilitates the collection of 'good quality' retrospective data from farmers
- Classical econometric analysis can provide a more robust understanding of farmers' adoption decisions if supported by historical data

**Abstract**
Farm level factors continue to be the mainly investigated factors for adopting innovations. This research explores how the adoption of agroforestry innovations is associated with the farm level conditions of the farmers over time. Retrospective data was collected from 327 households on three agroforestry innovations. We analyzed all adoption events starting from the year at which a farmer began adopting the innovation over the next five times, irrespective of the calendar year. We discovered that adoption intensified in the 2000s, and the frequency of adoption is largely limited to two or three times. After initial adoption, 32.11%, 14.68%, 3.36%, and 0.92% of the farmers made second, third, fourth, and fifth follow-up adoptions of the specific agroforestry innovations, respectively. Farm size and family size are significant drivers of the adoption decision consistently; household decision-making pattern is important for making initial and second time adoption. Farming income is also vital to arrive at the second and third time adoption decisions. Livestock size is also associated with first time adoption. Farm level variables accounted for 55-70% of the variation in adoption decisions. Our study confirmed that farm level variables are still relevant to explaining decisions to adopt agroforestry innovations by smallholder farmers. The sequential analysis provided insightful information on the variability of factors affecting these decisions over time. Lessons based on this data and the extant literature are discussed for development and research.

**Keywords:** diffusion, multivariate, socioeconomics, retrospective survey, Ethiopia

## 1. Introduction

With changing human preferences, market conditions, and continuing climate change, farmers' adoption of new and adapted technologies remains essential and understanding the adoption processes and decisions for such innovations will continue to be a field of socioeconomic research. In the context of slow and marginal technological change in sub-Saharan Africa (SSA), adoption studies fill the knowledge gap related to the adoption decisions of farm households. The adoption studies ultimately provide actionable recommendations (Glover et al. 2016).

Concerning agroforestry (AF), the deliberate spatial and or temporal integration of trees with animals and or crops (FAO 2020), smallholders' adoption of innovative practices is considered slow and small (Zerihun et al. 2014). The need to continuously adjust farming practices to changing circumstances (Tow et al. 2011), the uncertainties related to their adoption (Jerneck and Olsson 2013), the necessary long-term commitment of resources (Marenya and Barrett 2007), the required level of knowledge (Barrett et al. 2001), the more challenging nature of AF technologies compared to traditional agricultural practices (Mercer 2004), the insufficient work in blending the local knowledge and AF practice (Pattanayak et al. 2003; Lubell et al. 2014) and the attributes of the technology (Rogers 2003) often explain the reluctance of farmers to adopt AF practices. Besides, goal conflicts, delivery mechanisms, policy context, and time lags between action and impact realization affect AF adoption (Wydra 2015). Identifying the type of tree species desired by smallholders and the trade-offs involved in adopting AF practices with other farm enterprises is fundamental (Smith and Mbow 2014). The investigation contributes to promoting AF practices as new business opportunities rather than merely for their environmental benefits, which was the predominant approach for a long time (Russell and Franzel 2004; Adimassu et al. 2016).

Past adoption research has identified a plethora of farm level factors that influence the smallholder farmers' AF, or AF innovations (AFI, the production of various newly and or lately introduced AF technologies), adoption decisions. For example, prior knowledge about AF practices (Jamala et al. 2013), positive perceptions (Meijer et al. 2015), and tangible benefits generated by AF production (Ajayi et al. 2008; Zerihun et al. 2014) fostered smallholder AF innovation adoption. Farmers with a relatively higher number of livestock, better education, higher income or wealth (Mutambara et al. 2012; Jerneck and Olsson 2013; Zerihun et al. 2014), larger farm size, longer farming experience, and the tradition of adopting other agricultural technologies (Zerihun et al. 2014) were more likely to adopt AFI. Likewise, possession of less favorable, i.e., sloping and degraded lands (Feder and Umali 1993; Zerihun et al. 2014), higher labor force (Sood et al. 2008), male household heads (Kiptot, Franzel 2011; Jerneck and Olsson 2013) of younger age and with cosmopolitanism behavior (Sood et al. 2008) were factors positively related to the adoption of AFI. Forging partnerships and linkage among stakeholders (Russell and Franzel 2004; Soete et al. 2010; Vignola et al. 2015), including establishing innovation platforms (Schiller et al. 2020), resulted in high adoption-diffusion of AF technologies.

Nevertheless, while yielding valuable insights in some cases, much of current adoption research suffers from conceptual inconsistency and limited explanatory power. Oca Munguia and Llewellyn (2020) stressed the lack of convergence toward a consistent explanation for why farmers adopt innovations regarding the analytical methods, and the choice of explanatory variables used to model adoption. Amare and Darr (2020) indicated that studies employing multiple regression models with farm level variables as independent variables explain only 27-48% of the variation in the data as revealed by their adjusted $R^2$ coefficients (Supp. Fig.1). The direction of the relationship for many variables however remains arbitrary and influenced by local factors, which are not well understood. Most previous adoption studies employed a cross-sectional research perspective that does not appropriately reflect the dynamic nature of farmers' decision-making (Amare and Darr 2020; Glover et al. 2016) partially explains these weaknesses, which continue to be a major shortcoming and criticism of conventional adoption research.

The aim of this paper is thus to alleviate this shortcoming by investigating how socioeconomic and plot characteristics (labeled as farm level factors) influence the AFI adoption decision of smallholder farmers over time. The AFI covered by this study are farm woodlots of *Acacia decurrens* (hereafter acacia), *Eucalyptus camadulensis* (hereafter eucalyptus), and *Yushania alpine* (hereafter bamboo). Woodlots are an important AFI system in Ethiopia that involve a variety of crop-livestock combinations. For example, the trees are intercropped with selected field crops during woodlot establishment or plantation. Later livestock are regularly left to graze between the AF trees, or the grass is harvested as livestock feed (Nigussie et al., 2020). The three AFI under study are widely cultivated, given their better relative economic benefits compared to farming, and government agencies promote the establishment of acacia and bamboo woodlots. Eucalyptus woodlot is expanding primarily due to farmers' initiatives. Yet, the government often discouraged eucalyptus due to its anticipated side effects, such as impoverishment of soils, high levels of water use, and allopathic effects (Amare and Darr, 2022).

We applied a sequential adoption analysis by employing a retrospective data set. Five adoption times, namely first or initial time, second, third, fourth, and fifth adoption times, are examined. These adoption times represent stepwise adoptions of AFI, one after the other, over successive years or agricultural production seasons. These successive adoption times occur either in immediate consecutive years or might happen over a period larger than one year or multiple years. Except for initial or first time adoption, we commonly use the term 'follow-up' adoption to refer to adoptions extending from second to fifth times. Likewise, any follow-up adoptions in this manuscript designate the establishment of the same AFI on additional plot (s) of land, irrespective of the status (i.e., whether wholly or partially harvested or unharvested at all) of the initial or previous establishments. Also, follow-up adoption does not necessarily refer to changing the status of the initial or previous adoptions. Finally, increased, maintained, and reduced adoption refers to follow-up adoptions or expansions of the previous adoption extent. Increased means expansion adoption or follow-up adoption (i.e., following the immediate previous adoption) where the amount of current (i.e., referring to the specific adoption time) adopted AFI is higher than the previously adopted AFI measured in farm size or hectare units. Similarly, reduced refers to follow-up adoption or expansion where the extent of the current adopted AFI is relatively smaller compared to the preceding adopted AFI measured in farm size or hectare units. Finally, maintained adoption is follow-up adoption or expansion where the extent of current AFI adopted is identical in farm size or hectare units compared to the preceding adoption time.

We conducted our study in Ethiopia, where AFI adoption by smallholder farmers has increased significantly over the last few years (Wondie and Mekuria 2018). More precisely, we investigate (1) how the AFI disseminated among farmers throughout five successive adoption times; (2) how many farmers expanded, maintained, or reduced their AF adoption in follow-up times; and (3) which farm level factors influenced the farmers' adoption and expansion decisions. In doing so, we aim to contribute to the literature to help close current knowledge gaps by (i) conceptualizing adoption as an assembly of consecutive decisions leading to dynamic temporal and spatial outcomes against the current static adoption view, (ii) employing a mix of methods to reveal follow-up adoption decisions over time and space as a continuous process using retrospective data in contrast to standard practices of cross-sectional static and dichotomized adopt vs. non-adopt concepts, and (iii) providing scientific proof as the basis for effective AFI development interventions in comparison to current partially ineffective, incomplete and outdated scientific evidence.

## 2. Analytical framework

Previous research on AF adoption revealed that farmers are aware of the various benefits of trees, and their motivation to adopt AF practices is influenced by several confounding factors (Amare et al. 2019). Despite its shortcomings, Rogers (2003) diffusion of innovations theory remains the implicit conceptual foundation of most adoption studies (Hoffman 2007). Many adoption studies and other limitations have focused on the decision event rather than the adoption process, thereby limiting their contribution to development and research (Glover et al. 2016). We, therefore, conceptualize adoption as an evaluative process (Rogers 2003). After evaluating at different points in time, we assess the adoption decision farmers make, acknowledging that such decisions can be reversed in response to changing circumstances or time. Such a dynamic view acknowledges that the outcomes of the decision-making process are not fixed. In addition to retaining the original adoption decision, farmers can subsequently expand, maintain or reduce their AF practice, or entirely dis-adopt the innovation. We further envisioned that this dynamic adoption process over follow-up adoptions is mediated by farm level variables of farm households (Fig. 1). By employing a process analysis of farm level factors, we hope to address shortcomings originating from the limited cross-sectional view of most previous research.

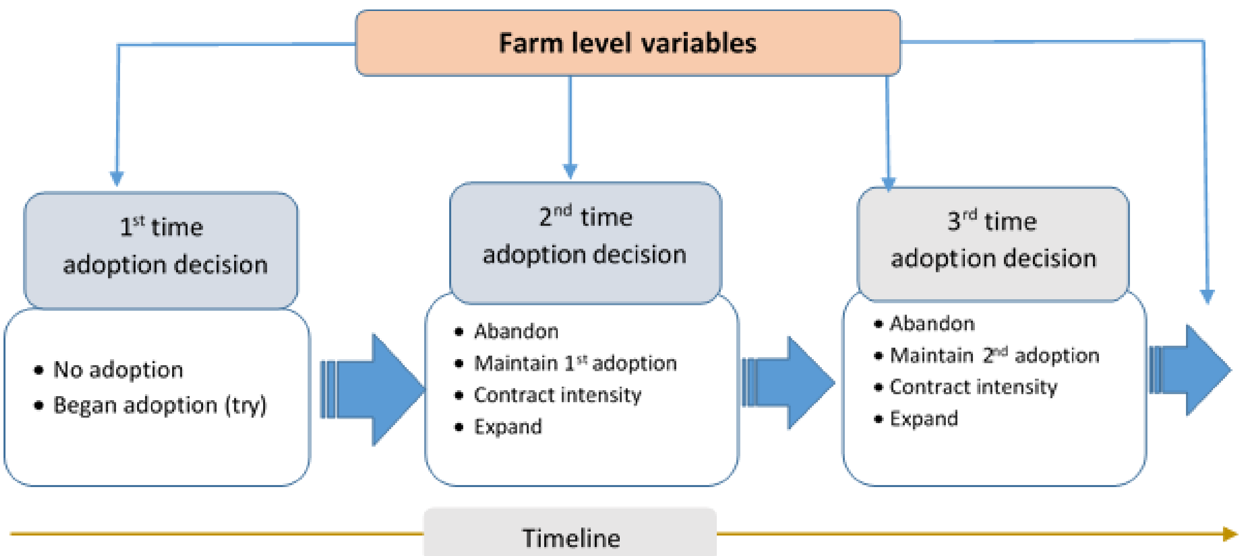



Figure 1. AFI adoption as an evaluative decision output across times of adoption (source: developed from Amare and Darr 2020; Rogers 2003)

The employment of this analytical framework using retrospective data conceptually contributes to an improved understanding of smallholder motivations, success factors and desired outcomes of AFI diffusion as it explores the dynamics of the adoption decision-making process, which ultimately contributes to increasing the benefits and welfare of smallholders in Ethiopia and SSA (Mercer and Miller 1998; Mercer 2004).

The use of cross-sectional data has been frequently criticized as it conceals the broader adoption decision contexts (Amare and Darr 2020; Glover et al. 2016). Likewise, using the desired longitudinal data where farmers are repeatedly monitored over several years is rare as it is expensive to obtain. As a remedy, retrospective data collected during a single interview can serve as a proxy in smallholder agricultural decision contexts spanning several times. To diminish data integrity concerns and recall errors related to the retrospective survey (Weinger et al. 2003; Gibson and Kim 2005), we applied triangulation techniques (Assaad et al. 2018). Eventually, a retrospective inquiry is applied to understand smallholders' dynamics in AFI adoption decisions over successive times.

## 3. Methods

**Study area**: The study was conducted in three districts of the Amhara region of Ethiopia. Ethiopia is a North East African nation of around 120 million individuals. It is a landlocked country, and 80% of the population is engaged in agriculture (World Bank 2022). Consequently, agriculture, including AFI production, is the main economic activity and source of livelihood. Amhara region is one of the ten administrative regions located in the North-western part of the country (11°39′39″N 37°57′28″E) and has a population of more than 22 million (Amare et al. 2016; CSA 2022). The districts are Mecha, Fagita and Banja. Mecha (11°29'59.99"N 37° 00' 0.00" E) offers favorable conditions for agricultural production with good soil fertility, slope and mid-highland climate conditions. Fagita (11° 19' 60.00" N 36° 44' 59.99" E) and Banja (11° 09' 60.00" N 36° 14' 60.00" E) districts have limited crop diversification opportunities due to poor soil fertility (Amare and Darr 2022).

**Data collection:** This study aims to investigate the factors that determine innovation adoption, specific to the three AFI and aggregated over several times of adoption. Our farm-household-level data consist of the adoption decisions of sample households recorded over successive times and covering a time horizon of up to 50 years for selected farmers. The questionnaire was framed as (1) in which year did you begin practicing this AFI, and at how much land did you adopt it? (2) in which year did you expand the AFI to another plot or increased the existing plot, and by how much area? (3) in which year did you plant the specific AFI for the third time, and at what area of land? (4) in which year did you plant the specific AFI for the fourth time, and at what area of land? and (5) in which year did you plant the specific AFI for the fifth time, and at what area of land? The questionnaire was limited to the maximum of five adoption times due to a lack of further adoption times and limited recall capacity observed during pilot testing. Data was collected from 327 households from June to August 2019. A multi-stage sampling procedure was employed by purposively selecting the districts and AFI, then choosing farmers who are or have been practicing the AFI. Farmers' final selection followed a simple random sampling procedure and a proportionate sample size technique. Data on connections among individuals-social networks and norms of reciprocity and trustworthiness (i.e., social capital) (Aldrich 2012) is probed from three perspectives. The three social capital (SC) perspectives are bonding, bridging, and linking. Bonding SC denotes connections among homogenous groups of people, whereas bridging SC refers to connections with heterogeneous groups. Additionally, linking SC represents vertical links of farmers with organizations and entities. Binary response questions, namely (a) Yes (have the specific link) and (b) No (do not have the specific SC), were employed to examine the farmer's status on the above SCs. Besides, data on the decision making pattern within a household on the adoption of AFI (household power index) was categorized as (1) consulting type (the household head makes the final decision after consulting with the family members), (2) balanced type (the household head and the spouse decide jointly), and (3) absolute type (the household head makes the final decision himself or herself).

**Data analysis**: Data analysis begins by aggregating the average seasonal adoption of each innovation by individual farm households comparing the respective initial year of adoption, independent of the calendar year. The years of adoption hence represent any calendar year a respondent indicated as the time when he or she adopted for the first time (first time adoption), and or made further follow-up adoption decisions (second to fifth time adoption) whether on a new plot of land, expansion to an adjacent plot, or replanting after harvesting the trees on the initial plot. After data aggregation, descriptive statistics and econometric models were employed for data analysis. Bi-variate tests were employed to show the significance of differences among the three innovation practices. While panel data is typically analyzed using time-series analysis models, the absence of consistent calendar years of adoption in our data (Supp. Fig.2) enforced the use of a multivariate multiple regression model. In the model, three dependent variables were regressed against a list of independent variables. The use of the model comes from our assumption that the adoption rate in subsequent years is correlated as farmers will evaluate the benefits of the first time adoption and, based on their assessment, make follow-up adoption decisions. We, therefore, employed the multivariate multiple regression model to capture this correlation. The multivariate regression analysis examines the factors affecting adoption for the three adoption times, i.e., first, second and third. The fourth and fifth time adoptions are excluded from regression inquiry due to the few numbers of AFI adopters in these adoption times, which are incompatible for regression analysis.

## 4. Results and Discussion

### 4.1. Summary of farm level characteristics

On average, the farmers were 47 years old, with farmers engaged in bamboo woodlots significantly older and those practicing acacia AFI relatively younger. The average livestock eucalyptus AFI practitioners owned was significantly higher than those in acacia and bamboo (Table 1). Similarly, bamboo producing farmers owned significantly larger livestock than farmers practicing the acacia AFI system.

Table 3. Summary of farm level characteristics

| Variables | Innovation type | | | |
|---|---|---|---|---|
| | Acacia (107) | Bamboo (88) | Eucalyptus (132) | Combined (327) |
| Age (years) | 43.46(±1.32) | 50.86(±1.30)*** | 46.60(±1.01) | 46.73(±0.70) |
| Female headed households (%) | 4.89 | 4.28 | 3.67 | 12.84 |
| Male headed households (%) | 27.83 | 22.63 | 36.70 | 87.16 |
| Farming experience (years) | 23.65(±1.45) | 30(±1.50)*** | 25.67(±1.09) | 26.16(±0.77) |
| Formal years of schooling (year) | 3.01(±0.40)*** | 1.39(±0.31) | 1.09(±0.20) | 1.79(±0.18) |
| Literate (% of households) | 15.03 | 14.42 | 20.86 | 50.31 |
| Illiterate (% of households) | 17.48 | 12.58 | 19.63 | 49.69 |
| Total family size (no.) | 5.41(±0.23) | 6 (±0.25) | 5.92(±0.21) | 5.77(±0.13) |
| Livestock (herd) size (TLU) | 3.14(±0.25) | 3.90(±0.24) | 4.07(±0.17)*** | 3.72(±0.13) |
| Farm income (ETB) | 9718(±1968) | 2800(±879) | 15227(±2024)*** | 10080(±1099) |
| Nonfarm income (ETB) | 2140(±805) | 1623(±412) | 1385(±337) | 1696(±316) |
| Total average income (ETB) | 16941(±2859) | 10367 (±3633) | 31045(±3811)*** | 11776(±1144) |
| Farm size (ha) | | | | |
| Owned | 0.79(±0.069) | 0.93(±0.061) | 1.09(±0.062) | 0.95(±0.038) |
| Total (owned+ rented+ shared) | 1.18(±0.072) | 1.08(±0.065) | 1.32(±0.065)** | 1.21(±0.04) |
| Asset ownership (% of households) | | | | |
| Mobile phone | 21.74 | 10.74 | 29.45*** | 61.66 |
| TV | 2.76 | 0.31 | 0.92 | 3.99 |
| Radio | 12.58 | 8.28 | 17.18 | 38.04 |
| Horse cart | 1.53 | - | 18.10 | 19.63 |
| Bajaj (3 wheel motor vehicle) | 0.61 | - | 0.92 | 1.53 |
| Solar panel | 12.58 | 5.83 | 26.99 | 45.40 |
| Housing (no of corrugated sheets) | 71.28(±3.32) | 89.16(±7)*** | 86.11(±2.78) | 82.38(±2.50) |
| Agroecology (% of households) | | | | |
| Humid | 6.73 | 26.30 | - | 33.03 |
| Sub-humid | 25.99 | 0.61 | 40.37 | 66.97 |
| Soil type (% of households) | | | | |

| | | | | |
|---|---|---|---|---|
| Red soil | 27.15 | 14.09 | 38.49 | 79.73 |
| Social capital type (% of households) | | | | |
| Bonding | 28.85 | 22.95 | 34.75 | 86.56 |
| Bridging | 29.97 | 26.3 | 38.84 | 95.11 |
| Linking | 30.45 | 28.95 | 36.84 | 96.24 |
| Household decision power index type (% of households) | | | | |
| Consultation | 16.39 | 9.45 | 13.68 | 39.41 |
| Balanced | 9.45 | 11.07 | 24.10 | 44.63 |
| Absolute | 6.19 | 6.19 | 2.28 | 14.66 |

Numbers in brackets represent standard errors; *** p< .01; **p< .05; *p< .10.; the significance refers the statistical difference among the three AFI and values where significance marks attached represent the significantly greater value compared to the other two groups; 1USD=20.445ETB as shadow price (i.e., average exchange rate of ETB to USD 20.8138 ETB/$1USD adjusted to the average USD inflation rate of 1.77% in the years 2010-2019).

Eucalyptus producing farmers owned significantly larger farms, were more likely to own mobile phones, and had a higher total annual income. Besides, bamboo producing farmers possessed significantly longer farming experience, while acacia producers were relatively better educated. Asset ownership, particularly of three-wheel motor vehicles, solar panels, and TV sets, was associated with acacia and eucalyptus but not bamboo adopters, demonstrating that market factors and better income could lead to investments or acquisition of household amenities.

Regarding social capital, the adopters of the different AFI showed largely similar patterns. A higher percentage of eucalyptus farmers had close ties with family and friends or neighbors (bonding social capital), outward-looking networks across socially heterogeneous groups (bridging social capital), and vertical networks with government and NGO entities (linking social capital) compared to both acacia and bamboo producing farmers. The values were, however, not significantly different across innovations.

Household power index illustrates that consultation-type decision making was dominant in acacia producing farm-households. In contrast, farming households producing bamboo and eucalyptus adhered mainly to the balanced decision-making type. Absolute decision making pattern prevailed in only a few households (Table 1).

### 4.2. Adoption trends and diffusion

In this manuscript, a non-adopt state of farmers (i.e., whether in Fig. 2, Sup Fig. 2 or in narrations) does not imply that the farmers immediately ceased or removed the production of the initially established AFI. Instead, it exclusively refers to suspending further, follow-up establishments of the same AF innovation on a new farm plot. In reality, given the longevity of AFI, most follow-up adoptions take place with the previously established AF still prevailing on the plot. Generally, bamboo and eucalyptus in the study areas largely exhibit long-lasting life cycle; whereas the life cycle of acacia ranges between four to six years. Below we discuss the adoption decisions based on specific time frames in which the initial and follow-up adoptions happened.

**Bamboo:** bamboo is the oldest AFI woodlot adopted by farmers (Supp. Fig.2). Bamboo adoption began in 1959 when the oldest respondent of this study planted bamboo while founding a family, detached from his ancestors. During the subsequent decades (i.e., from the 1960s up until 2005), the number of new families annually establishing bamboo fluctuated between 2 and 4. No new adoptions were recorded for the years 2006 and 2007. Conversely, 2008 and 2009 showed higher bamboo adoption rates: on average, 6.5 new farmers adopted bamboo annually. Ironically, after 2011 fewer families (i.e., on average 3.5) adopted bamboo. Overall, the adoption trend of bamboo from the 1960s up to 2019 remained more or less consistent. Farmers' preference towards a modest amount of bamboo production due to marginal market orientation is one of the logics for the comparable annual bamboo adoption rate. Furthermore, farmers revealed that their primary target of bamboo adoption is home consumption. This consumption-based (e.g., for house construction, fencing, local furniture) adoption is related to forming new or young families or couples. This long-established adoption tendency is, thus, limited due to fewer new or young families formed in these locations in recent years.

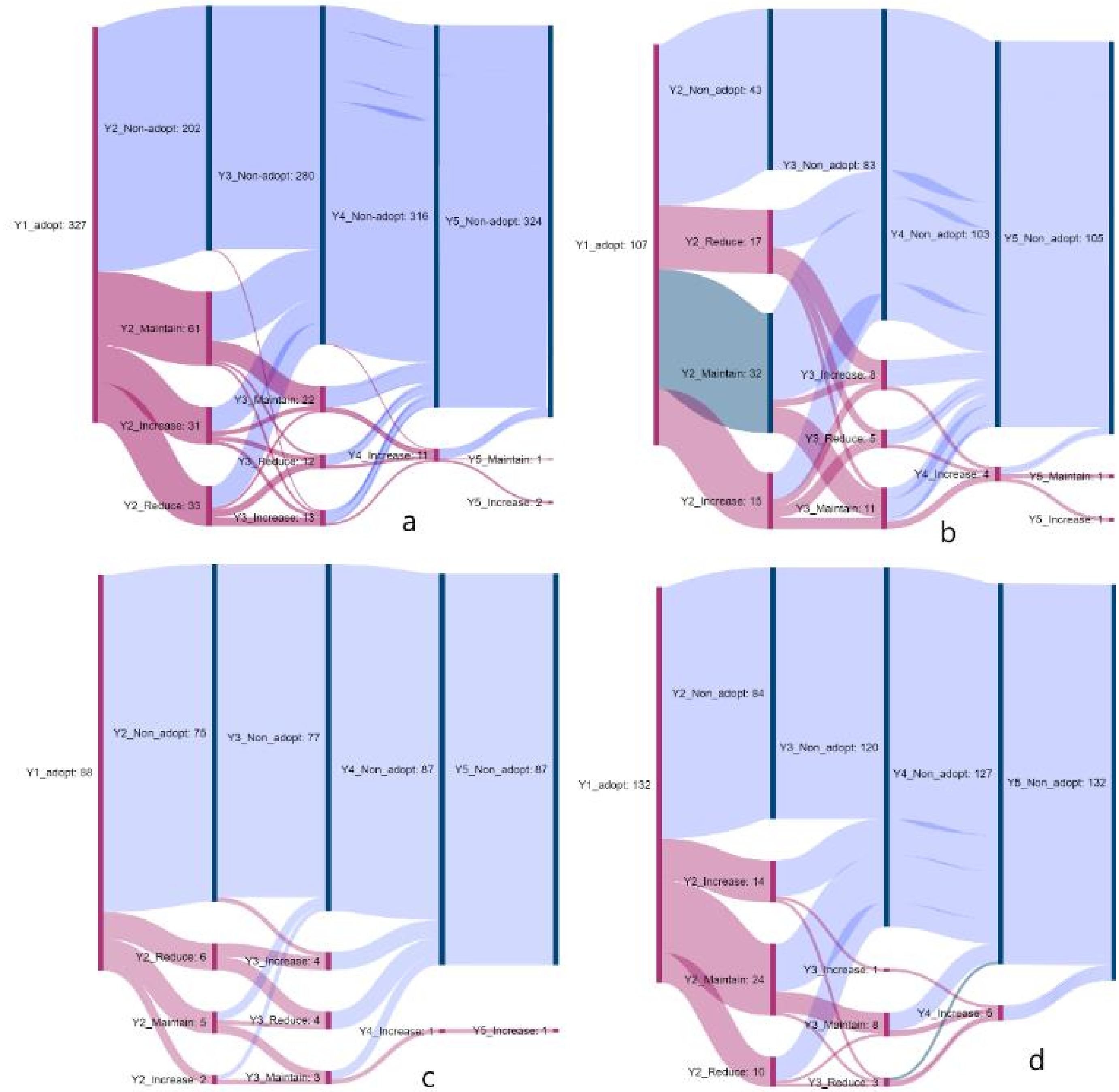



Figure 2. Times of adoption decisions over years (a=grand, b= acacia, c= bamboo, and d= eucalyptus; Y1= year 1, Y2=Year 2, Y3=Year 3, Y4=Year4 and Y5=Year5); nodes represent season or year of adoption, density of links represents numbers.

For the follow-up adoption decisions (Fig 2 c), almost 15% of farmers expanded their bamboo woodlot to new or adjacent plots for the second time. Yet only 2.3% of them implemented a greater extent of adoption during the second time than their initial adoption. In contrast to their initial adoption, 5.68% and 6.82% of farmers adopted comparably identical or reduced amounts of bamboo, respectively. Nonetheless, most farmers (85.23%) never expanded their initial bamboo adoption.

Several farmers (12.5%) expanded their bamboo production during the third follow-up adoption. These farmers either carried out a reduced (4.55%) or an increased (4.55%) extent of bamboo adoption during the third time, while 3.41% of farmers carried out third time adoptions on a level equal to the previous, second time adoption. Merely 1.14% of farmers in our bamboo study area expanded for the fourth and fifth times. These expansion adoptions were incremental compared to the previous third and fourth times.

**Eucalyptus:** eucalyptus adoption in the study area started in 1976 and continued until 2019. However, between the 1970s to 2002, new adopters of eucalyptus were rare (Supp. Fig. 2). Non-acquaintance of the farmers with the attributes and benefits of this newly introduced species and the dependence and or availability of indigenous tree species for all sorts of home consumption (e.g., energy, construction) are the logics for low eucalyptus adoption in these early days. The exclusion of meager adoptions (i.e., only a few trees, ranging from one to ten around homesteads) in our survey is another possible explanation for the observed low adoption rates during the early days. In later years (i.e., between 2003 and 2019), an average of 7 new farmers adopted eucalyptus annually. The unfolding of huge market opportunities around the millennium and the formation of a relatively larger number of new families are the causes for this noticeable change in adopter numbers compared to the preceding years, as understood from our discussions.

About expansion decisions, 36.36% of families implemented further second time adoptions (Fig.2 d). Nearly 11% of these families expanded their AFI at an increased rate compared to their initial adoption. Other farmers expanded their AFI adoption by an almost identical (18.18%) or reduced (7.58%) extent compared to the first time adoption. Only 9% of farmers expanded their eucalyptus AFI for a second time (i.e., carried out adoption for the third time). These adoptions followed maintained (6.1%), reduced (2.27%), or increased (0.76%) adoption directions compared with the second time adoptions. A small fraction (3.79%) of farmers expanded for a third time by carrying out fourth time adoptions. Fourth time adoptions were entirely increased adoptions relative to the farmers' respective third time adoptions.

**Acacia:** acacia is the 'newest' AFI introduced and adopted in the area. Acacia adoption began in 1995 and continued until 2019 (Supp. Fig.2). With only 6 new adopters per year, the diffusion of acacia until 2010 was marginal. However, a trend of first time acacia adoption commenced in 2011 and continued up to 2019.

Follow-up adoption for acacia was relatively high compared to bamboo and eucalyptus, especially on the second and third times (Fig 2 b). Sixty percent (60%) of farmers made expansion decisions by undertaking second time acacia adoptions. These expansion decisions followed increased (14%), maintained (30%), and reduced (16%) directions compared to the initial adoption. Furthermore, 22.43% of farmers expanded their acacia production on new plots by making third time adoptions. These followed increased (7.48%), maintained (10.28%), or reduced (4.67%) patterns compared to the second time. Acacia expansion continued as farmers made fourth (3.74%) and fifth (1.84%) time adoptions. Fourth time acacia adoption entirely followed an increased pattern, whereas during fifth time adoptions, farmers pursued increased (0.93%) and maintained (0.93%) patterns.

All investigated AFI featured a first time adoption wave between 2012 and 2018. This adoption wave coincided with earlier efforts of the government to promote agricultural commodities in the context of local resources and development strategies. For example, acacia was selected as the most promising agricultural and AFI in Fagita Lekoma district in 2004. As revealed by key informants, innovative individuals developed charcoal from their acacia plantations. Profitable product (i.e., charcoal) development, consumers' preference for acacia tree based charcoal, and local market saturation led to the enactment of subsequent product transport regulations. The government formulated these regulations with the lobby of early charcoal producers. For instance, certificates are offered to farmers proving the acacia and charcoal are produced from their plots and not harvested from natural forests. Overall, the adoption waves for acacia emerged from better knowledge of the utilization of acacia, government promotion, and expanding market opportunities for acacia products, as recounted by district experts. Meanwhile, the eucalyptus adoption wave was related to its multiple consumption benefits (e.g., construction, fuel, cash), soaring demand in the construction industry, establishment of wood processing factories in the North, and export opportunities to Sudan.

In general, follow-up adoptions and expansions followed downward sliding (survivor) curves (Supp. Fig.3). Most farmers solely carried out first and second time adoptions, never expanding beyond these. Overall, the farmers in our study areas (Fig 2a) undertook second (32.11%), third (14.68%), fourth (3.36%), and fifth (0.92%) time adoption of the respective AFI.

Furthermore, despite the amount of non-adoption cases concerning follow-up times, farmers continued to produce the AFI already adopted. The follow-up adoption decisions declared by farmers were counted irrespective of the state of prior adoption. The previously adopted AFI might still survive on the plot while a farmer makes subsequent expansion decisions. AFI from the previous adoption time might still be located on the plot either as unharvested trees or as growing, harvested stumps. For example, an acacia farmer might continue to adopt for follow-up adoption while the initially adopted AFI is still under production on a separate farm plot. Alternatively, he or she might carry out a follow-up adoption in the same plot of land after fully harvesting the previously established acacia. As farmers strive to benefit from existing, vast market opportunities, we observed farmers making follow-up adoptions while their previous establishments were still under production (i.e., either as newly planted seedlings or matured and ready for harvesting).

For the other AFI (i.e., bamboo and eucalyptus), follow-up adoptions occurred, whereas the initially established was yet under production. In the case of eucalyptus, farmers' follow-up adoptions occurred on new plots of land as eucalyptus is regularly not uprooted during harvesting. Eucalyptus can be regarded as a perennial or at least a permanent tree on that particular farm plot, as uprooting eucalyptus is a rare practice in the observed localities. Regarding bamboo, follow-up adoptions occurred either on new farm plots with the previously established bamboo still existing or might be adopted by uprooting the initially established bamboo. Given the longevity attribute of eucalyptus and bamboo, follow-up adoptions for these AFI predominantly occurred with the previously established AFI plots yet under production.

Concerning plot allocation, the largest farm area was allocated during the fourth (1.51ha±0.39) and fifth (1.4ha±0.31) adoption times (Fig. 3). Despite the arithmetic difference, the areas allocated during fourth and fifth time adoptions are statistically not significantly different across AFIs. This may imply that, as farmers continue to experiment, experience, and gain knowledge of the practice and benefits, the likelihood of expansion increases over the years. Yet, as revealed during discussions and key informant interviews, knowledge alone does not drive AFI expansion; other factors include market and home consumption benefits. Acacia expansion, for example, is associated with vast market opportunities (i.e., for its charcoal product), both in local and national markets.

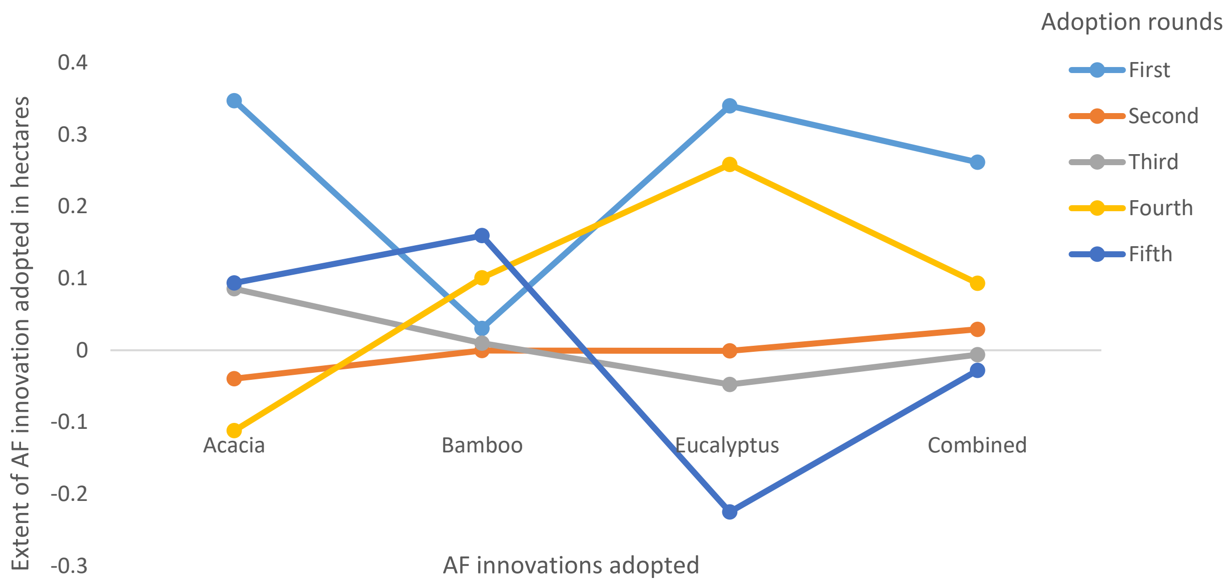



Figure 3. Change in adoption extent across times

Innovation attributes might additionally hinder follow-up or expansion adoptions. The perennial nature of eucalyptus hampers farmers from making follow-up (whether one or more) adoptions, as the previously established plot cannot be freed from eucalyptus. With land resources being limited, farmers hence quit carrying out follow-up adoptions. In contrast, the disinvestment feature of acacia creates the opportunity to replant the harvested or freed plot or establish acacia in another plot, as it can easily be fully uprooted whenever needed. The case of bamboo is different yet again. Bamboo is largely established in riverine areas, grazing lands, homesteads, and plot borders. Establishment sites often are prone to destruction due to animals and humans. Due to poor management, destruction from animals, and poor market conditions, self-propagation is the predominant way of bamboo expansion in most of these sites. As reported by farmers and local experts, such marginal management and poor market opportunities hamper deliberate follow-up adoptions.

Regarding further statistical analysis, the pairwise correlation found a poor and non-significant correlation between the age of farmers and the extent of follow-up adoptions. The extent of follow-up adoption was, however, inversely related to the total cultivated land by farmers during the third and fifth times of adoption. The association of total cultivated land with third and fifth time adoptions indicates that younger families practically allocate their plots for establishing AFI, whether owned or rented. As understood during the fieldwork, younger families in acacia and eucalyptus AF systems usually establish these in their entire plots. Older families rely less on AFI production and focus on food production. Alternatively, older families marginally manage their AFI plots as they have rented out their plots due to labor shortages.

### 4.3. Determinants of AFI adoption

Due to the limited number of follow-up adopters on the fourth and fifth times, regression analysis was conducted only for the first three adoption times. Beyond ineligibility for standard regression analysis, such exclusion was necessary as the results cannot be generalized. The extent of AFI adopted, the dependent variable is measured in 'Kada' or 'Timad' (an Amharic word representing a quarter of a hectare) due to the small land ownership of the farmers and the difficulty in interpreting results in case we used the conventional hectare units.

Table 2 displays that farm size is positively and significantly correlated to AFI adoption concerning all three adoption times. The likelihood of AFI adoption increases by 0.063ha for the initial and second times and by 0.058ha for third time adoptions whenever a farmer owns one more 'Kada' of land. In contrast, family size is negatively and significantly correlated to the initial as well as the two follow-up adoptions: a unit increase in family size decreases the extent of AFI adoption by 0.033ha, 0.053ha, and 0.043ha, respectively, for first, second, and third time adoptions.

Herd size (TLU) is negatively correlated to initial adoption, as the ownership of a relatively larger size of livestock requires a higher amount of feed. A unit increase in herd size decreases the extent of first time AFI adoption by 0.043ha. In order to obtain sufficient animal feed from crop residues, farmers need to pursue traditional crop production. Otherwise, farmers with larger herd sizes allocate some of their plots for feed production instead of AFI investment.

Table 4. Multivariate multiple regression on adoption determinants

| Variables | | Times of adoption | | |
|---|---|---|---|---|
| | | First | Second | Third |
| **Age** | | 0.017(0.023) | 0.018(0.02) | -0.013(0.03) |
| **Years of schooling** | | 0.043 (0.033) | 0.023 (0.03) | -0.03 (0.043) |
| **Total farm size** | | 0.14(0.058)** | 0.14(0.05)** | 0.23(0.08)*** |
| **Family size** | | -0.13(0.07)* | -0.21(0.06)*** | -0.17 (0.09)* |
| **Farming experience** | | 0.006(0.017) | -0.0004(0.014) | 0.011 (0.022) |
| **Social capital index** | | 0.94 (0.85) | -0.33 (0.71) | -1.48(1.11) |
| **Livestock in TLU (herd size)** | | -0.17 (0.07)** | -0.015 (0.056) | -0.082(0.09) |
| **Farming income** | | 4.94e-06(4.66e-06) | 9.92e-06(3.89e-06)** | 1.62 e-05(6.08e-06)** |
| **Non-farm income** | | -1.13e-05(2.48e-05) | 3.80e-06(2.07 e-05) | 6.73e-06(0.0000324) |
| **Asset index** | | 0.82 (0.64) | 1.12 (0.53)** | 1.18 (0.83) |
| **Household power index** | Absolute | -0.82 (0.34)** | -0.55 (0.28)* | 0.016(0.44) |
| | Consultation | -0.35(0.24) | 0.25(0.20) | -0.35(0.32) |
| **Red soil type** | | -0.44(0.37) | 0.29(0.31) | -0.18(0.48) |
| **Constant** | | -0.08(0.97) | -0.09(0.81) | 2.29(1.27)* |
| **$R^2$** | | 0.5499 | 0.7005 | 0.6679 |
| **F** | | 1.88 | 3.60 | 3.09 |
| **P(model)** | | 0.0990 | 0.0051 | 0.0115 |
| **Wilks' lambda** | | | | 0.0669*** |
| **Pillai's trace** | | | | 1.6858*** |
| **Lawley-Hotelling trace** | | | | 5.0673*** |
| **Roy's largest root** | | | | 3.3217*** |

Multivariate regression model, Number of observations: 34; numbers represent coefficients and standard errors in brackets. ***p< .01; **p< .05; *p< .10. The dependent variables are measured in 'Kada' or 'Timad'. The land unit is kept with the local measurement in 'Kada' or 'Timad' (0.25ha) due to the generally total small farm size (on average <1ha) ownership of our target farmers (Table 1). A cross-sectional regression analysis as a comparison is provided in the appendix Table 2.

Regarding decision making patterns, absolute type farm households have a negative association to initial and second time AFI adoption. Switching a farm household from a consultation or a balanced type to an absolute type decreases the extent of initial and second time adoptions by 0.21ha and 0.14ha. Farming income is correlated positively with second and third time adoptions. A hundred ETB increase in farming income increases the extent of second and third time AFI adoption by 2.48m$^2$ and 4.05m$^2$, respectively. Additionally, a unit increase in the asset index of a farmer increases the extent of second time AFI adoption by 0.28ha.

### 4.5.Discussion

Chronologically, farmers adopted acacia, eucalyptus, and bamboo starting from the most recent. Taken together, 51% of our study farmers carried out follow-up adoptions of various amounts (Fig. 2 and Fig. 3). Looking at specific AFI, a cumulative 87.85% and 29.55% of farmers carried out follow-up adoptions of acacia and bamboo, respectively. A combined 49.24% of farmers carried out follow-up eucalyptus adoption. Yet, the follow-up adoption for eucalyptus was limited up to the fourth time. The number of farmers carrying out follow-up adoptions decreased smoothly for all of the investigated AFI (Fig.5). We discuss the relation in contrast to extant literature.

Adoption is facilitated by different contexts, such as biophysical, farm level, and institutional conditions (e.g., Adimassu et al. 2016; Dessie et al. 2019). As revealed during group discussions, the primary factor for the initial adoption of bamboo and eucalyptus was home consumption, whereas market opportunities were concrete factors of acacia adoption. In this connection, it is worth highlighting that government efforts had previously promoted acacia, mainly as a natural resource management strategy (World Bank 2020). Following the primary factors, farm level features strongly affected the intensity of adoption, as confirmed by allocated land and frequency of follow-up adoptions. Results of Table 3 display that among the 13 variables used in the models, four, five, and three have a critical impact on making the initial, second, and third time adoptions, respectively.

Amid the considerable variance of the importance of farm level variables, farm and family size consistently (despite different directions of relationship) influenced AFI adoption, both initial and follow-up adoptions. As the farm size increased, the likelihood of AFI adoption increased correspondingly. General availability of spare plots of land for AFI in excess of main crop production activities, availability of additional land from rented-in or shared plots, aspiration of farmers to engage in AFI due to satisfied (for home consumption and earnings/marketing) crop production, intentions to circumvent the tedious efforts of conventional farming by establishing less arduous farm enterprises such as AFI, and or the preferential switching of farm plots from crop to AFI production due to anticipated or exhibited financial gains and or due to costly inputs or poor performance of agricultural commodity prices positively influence farmers adoption of AFI. These findings corroborate with studies from a cross-sectional context (e.g., Zerihun et al. 2014). Nevertheless, Abiyu et al. (2016) found a positive and paradoxically negative association of farm size with the total number of AF trees and the density of trees, respectively. A recent review disclosed the absence of a linear relationship between adoption and farm size (Amare and Darr 2020); instead, sometimes a positive (36%), occasionally negative (6%) correlation, and often no association (58%). The divergence of our results is due to the consideration of AFI woodlots in this manuscript vs. the focus on traditional AF (i.e., maintenance of few trees or shrubs for mainly consumption activities and hardly managed) and the contrasting treatment of the variable (Nigussie et al.2017). For instance, we executed the entire available land for the farm family in the econometric model, whereas researchers incorporated the area of cultivated land.

Anticipated food shortages, correspondingly high food consumption needs, desire for short-term crop production farm activities, and availability of spare labor for intensive crop management deterred or diminished farmers' engagement in AFI investment. Consequently, family size is inversely related to AFI adoption. These findings both corroborate (e.g., Amare et al. 2019; Abiyu et al. 2016) and diverge (e.g., Sood et al. 2008) from the results of cross-sectional studies due to differences on focus of research (i.e., our focus on AFI woodlots vs. other studies focus on traditional AF) and the alternative treatment of the variable (Nigussie et al. 2017). Amare and Darr's (2020) review yet manifested inconclusive results, with family size periodically being positively (24%), seldom negatively (0.24%) correlated, and often un-associated (75%) to AFI adoption.

The adoption extent of AFI correspondingly decreases as livestock or herd size increases. Perceived feed shortage due to the predominant reliance of farmers on crop residues and the reduction of crop residue in case plots are switched/retracted to AFI production, the strenuous livestock management requirements due to the establishment of exclosures (or stall feeding instead of free grazing) in formerly communal grazing lands (Amare et al. 2017; Mekuria et al. 2021), the desire to keep a relatively larger livestock herd for the various farm activities such as plowing, trampling and transporting and the preferential allocation of grazing lands for feed production or for refugee purposes shrinks the prospect extent of first time AFI adoption. Yet, extensive research (Abiyu et al. 2016; Mutambara et al. 2012; Jerneck and Olsson 2013) has demonstrated a positive association of herd size with AF adoption. Disconnection of herd size with follow-up adoption decisions is linked to herd maintenance with poor or minimum management, the slow-paced switching (or desire) to AFI based production system from the primary crop-livestock based agricultural production system, gradual shrinkage of herd size due to feed shortage effect of the new AFI production system, or the traditional secondary position (i.e., less importance) of livestock production (Mekuria et al. 2021; Amare et al. 2017) prove the unimportance of herd size for subsequent adoption decisions. The effect of herd size will be negligible in the context of gradual AIF adoption. Farmers testified, and we observed modest farming system transitions, especially in acacia and eucalyptus AFI systems. Farming system transition in acacia farming systems was confirmed in a bio-physical study (Wondie and Mekuria 2018). Indeed a review (Amare and Darr 2020) of cross-sectional studies proved the inconsistent relationship between AFI adoption and livestock ownership, alternating between positive (25%), negative (12.5%), and no-association (62.5%).

Farming income is positively linked to second and third time AFI adoptions. We interpreted it as a proxy for investment capital, and hence farmers' financial demand for further intensive production inflates. Acquisition of additional or sufficient income from farming activities also allows farmers to seek rental plots for establishing AFI. Earning disposable income from traditional crop production improves the likelihood of follow-up adoptions. Our findings corroborate studies that demonstrated a positive association between income and increased likelihood of AFI adoption (Mutambara et al. 2012; Zerihun et al. 2014). The recent review (Amare and Darr 2020) found that farming income is more often positively (20.83%) rather than negatively (12.5%) associated with adoption, yet in most cases, not associated at all (66.67%). For knowledge purposes, the absence of association between farming income with first time adoption is linked to the needfulness of capital during the initial or trial adoption stage that largely involves learning processes (Rogers 2003), and where farmers make predominantly meager adoptions

Availability of different assets, linked to the accessibility of investment capital, is positively significantly correlated to second time adoption. AFI being capital-intensive, e.g., for securing seed or seedlings, establishing seedlings, and subsequent management activities such as weeding, the availability of capital increases the likelihood of adoption. The availability of employable resources to produce AFI woodlots, including tools to access market information, reinforces AFI adoption. Yet initial and third adoption are not influenced by assets, presumably due to meager (i.e., consumption or pilot level) adoptions during the initial pilot stage with no demand for substantial capacity investment capital and the desire for farmers to take risks that could be deleterious without the help of assets such as market information, respectively. Indeed Amare and Darr’s (2020) summarized asset index category, wealth status, proved positive (9.1%) or negative (9.1%) and, in most cases un-association (81.8%) AFI adoption decisions.

A farm family predominantly exhibiting an absolute type of household power index is negatively correlated with initial and second time AFI adoption. Farm families where heads decide dominantly prefer to engage in traditional crop production and only show limited interest in AF investments. Perceived own capability of managing traditional crops better than AFI (Meijer et al. 2015; Amare and Darr 2022; Ajzen 2011), the desire to reduce risks from potentially poor AFI production (Zerihun 2020), the perceived gap between AFI establishment and benefit realization, and the urge for immediate home consumption needs, are credible justifications for the plummeted interest of farmers in AFI adoption in absolute type farm families. The current focus of extension advisory services on crop production and the influence of neighbors and siblings on hitherto crop production are also presumed causes for a lower interest in AFI establishment within these families. Nigussie et al. (2017), Kiptot, Franzel (2011), and Jerneck and Olsson (2013), by employing the proxy gender variable, found that male headed households are positively correlated with AFI adoption.

We further validated six suggestions from previous research (Amare and Darr 2020). With 23-38.5% (Table 3) execution to significance ratio (i.e., the ratio of frequencies of a variable is inserted and significantly correlated with the dependent variable in econometric models), we corroborate previous research that farm level factors are frequently statistically associated to AFI adoption (e.g., Nigussie et al. 2017; Amare and Darr 2020).  We also exhibited the decreasing importance of farm level factors for follow-up adoption decisions. Our proposition 2 found that contrary to extensive research, our retrospective analysis demonstrated that effect size (coefficient) and significance levels vary across adoption times. For example, farm size is significantly linked to first and follow-up adoptions (Table 3); its significance level, however, varied from 1% (i.e., during the third time) to 5% (i.e., for the first and second time). Such results reveal an insight that the relationship between independent and dependent variables varies, both on existence and intensity of linkage, over time which can hardly be delivered from generic research (Mercer 2004; Pattanayak et al. 2003).  In proposition 3 our models displayed that 55%, 70%, and 67% of the variation for making AFI adoption is attributed to farm level variables and hence are essential for first, second, and third time adoptions, respectively. It thus corroborates the credible importance of this category of factors described by previous findings (i.e., between 27 and 48% explanation power) as summarized by Amare and Darr (2020). In proposition 4 as already substantiated (i.e., proposition 1-3), the retrospective scrutiny offered more insightful information on AFI adoption compared to extensive analysis (Table 3 and 4, Supp. Table 1). Beyond understanding specific factors affecting the initial and follow-up adoptions, this backdated examination unveiled the time specific and the level of importance of each executed variable in the continued adoption process. In proposition 5 we demonstrated the importance of overriding simplistic investigations by thoroughly configuring household power index. This further disclosed dissimilar effects (i.e., one significantly associated and another not linked) on AFI adoption decisions (Table 3). It, therefore, is necessary to realize that understanding household power decisions can bring more insightful information on factors affecting AFI adoption than simply employing gender disaggregated data. Farmers' different connections should be used differently for AFI adoption promotion (Zerihun 2020; Sanginga et al. 2007). In our thematic analysis (Table 2), we demonstrated that our study farmers have high levels of bridging and linking SC. Understanding the SC most favored supports the effectiveness of advisory services or development interventions (Fischer and Qaim 2012). Experts can also fill gaps created by deteriorating SC and fulfill development objectives (Leonard 2004). Overall, an exhaustive understanding of both farm family power distribution and the type and extent of linkages with other individuals and stakeholders is important for a more rigorous inquiry and better understanding. Finally, we displayed that the adopt/non-adopt treatment, as well as the static adoption concept, once after passing the five stages of decisions (Glover et al. 2016; Rogers 1983; Pattanayak et al. 2003), as often employed misleads as farmers make different adoption decisions after initial or pilot adoption. Farmers carried out initial adoption and follow-up adoptions (either increased, maintained, or reduced, Fig. 2). Other farmers quit making follow-up decisions (i.e., abandoned) after the first adoption time. Farmers thus followed dissimilar adoption directions afterward initial testing.

Despite a presumed huge contribution, this study is not without limitations. The major weakness of this study is ascribed to the regression of post-adoption decisions of farmers, traversing several years, against current information on these variables. Consequently, this model results barely captured the timely relationship between farmers' adoption decisions and their farm level contexts or variables. Model results largely illustrate a prospective scenario of adoption decisions against certain farm level factors. Due to this fact, retrospective data's benefit is less than panel data and time-series analysis with time dependent variables. Eventually, if improperly implemented, retrospective analysis can lead to misleading conclusions. In our research, however, triangulation on data probing was carefully conducted; hence, the errors related to data integration are minimized. Yet, we suggest (i) collection of time-series data, and (ii) improvement of retrospective data in case it is mandatory to collect retrospective data sets under smallholder contexts.

Regarding the collection of time-series data, student family members can be easily commissioned, with minimum cost (e.g., monthly/yearly educational incentives and books), to record timely/seasonal input–output magnitudes and costs and related investment decisions. In today's rural families in Ethiopia, where at least one family member, a child, attends schooling, it is easy to employ such data collection procedure. Second, local development agents can similarly be commissioned to record time-series data by providing data-recording sheets/forms. Moreover, when researchers collect retrospective data, due to whatever reasons, it is necessary that they also collect, despite possible huge errors to collect timely contexts of the variables instead of following a gruesome information collection approach. For example, the researcher can ask about the number of livestock, land size, access to extension service, asset ownership etc., during first time (and so on) adoption decisions. This, however, requires extended interview time, as farmers also need to be asked by attaching to remarkable events in their families such as the birth of a child, new achievements, challenges in their marriage etc. Minimizing the contents of the questionnaire and the required retrospective data period is important to increase farmers' recollection capacity and minimize fatigue. A few variables (e.g., age and family size) can also be extrapolated from the current data for each adoption stage as long as the adoption calendar year is known. In this research, due to possible conflicting contexts, as some variables can be calibrated while others are not concretely known for rectification, we evaded applying this adjustment approach to the values of some of these variables (e.g., age) to their time specific statistic.

## 5. Conclusion and implications

This study explored how farm level variables are associated with AFI adoption decisions. By employing a retrospective analysis, we found that farm level variables contribute 55-70% of the variation for making AFI adoption decisions. Significance to execution ratio also ranged between 23% and 38%, largely overlaying and confirming earlier conclusions.

Overall, farmers followed dynamic decision making contexts as they continuously make decisions to adopt or not-adopt and further make adjustments related to the extent of further adoptions, with some maintaining the initial investment, others expanding, and yet others adopting to a comparatively lower extent in contrast to their initial adoption. This information may assist efforts from development actors to more easily understand the vital level factors for specific adoption times. Further, policymakers can better be advised on exactly which factors are important for better adoption-diffusion of innovations. Consequently, policy guidelines can be formulated by following stepwise procedures, instead of crude policy directions, for both judicious use of human and material resources and ease of the farmers' adoption process. Applying a mix of thematic and econometric methods revealed the depth of information unavailable in common dichotomous models.

Retrospective scrutiny coupled with thematic analysis inferred more information by displaying the importance of variables across adoption times. Considering the depth of information, retrospective analyses unveiled itself as a superior approach compared to extensive analysis. If the adoption times had been on immediate sequential years (i.e., without gaps), the retrospective inquiry could even have been more informative by employing panel data analysis tools. By conducting this retrospective approach, we manifested adoption as a product of consecutive adoption decisions in contrast to the common static approach. Based on the results of this thorough investigation, we support the transition of enactment of development interventions and policy regulations from mere intuitions of individuals or incomplete information to more structured decisions based on sound scientific results.

While we stress the importance and further exploration of farm level variables, the selection and thorough configuration of some variables are warmly welcome. With many possible farm level variables and model restrictions (rule of thumb of maximum 13 variables), selecting variables to insert in econometric models requires a precaution. Hence, variables should be inserted based on literature reviews and preliminary field assessments.

By publishing this manuscript, we illustrate the importance of retrospective data and its seasonal effect on AFI adoption decisions. The approach highlights the adoption and diffusion process and is more reflective than the regular adopt and non-adopt perspective. Nevertheless, the collection of retrospective data can be problematic considering smallholder contexts. To overcome this, we advanced the tradition of recalling facts by attaching this with key events affecting smallholders' lives and livelihoods. Eventually, the manuscript may serve as a pacemaker and initiate a debate regarding collecting and using retrospective data under smallholder contexts for prospective and robust policy and development recommendations.

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**Supplementary file:** Appendix B.

**Publication bibliography**

Abiyu, Abrham; Teketay, Demel; Gratzer, Georg; Shete, Maru (2016): Tree Planting by Smallholder Farmers in the Upper Catchment of Lake Tana Watershed, Northwest Ethiopia. In *Small-scale Forestry* 15 (2), pp. 199–212. DOI: 10.1007/s11842-015-9317-7.

Adimassu, Zenebe; Langan, Simon; Johnston, Robyn (2016): Understanding determinants of farmers' investments in sustainable land management practices in Ethiopia: review and synthesis. In *Environ Dev Sustain* 18 (4), pp. 1005–1023. DOI: 10.1007/s10668-015-9683-5.

Ajayi, O. C.; Akinnifesi, F. K.; Mitti, J. M.; Wolf, J. de; Matakala, P. (Eds.) (2008): Adoption, Economics and Impact of Agroforestry Technologies in Southern Africa. Ecological Basis of Agroforestry. With assistance of D.R. Batish, R.K. Kohli, S. Jose and H.P. Singh: Taylor & Francis / CRC Press.

Ajzen, Icek (2011): The theory of planned Behavior: reactions and reflections. In *Psychology & health* 26 (9), pp. 1113–1127. DOI: 10.1080/08870446.2011.613995.

Amare, Dagninet; Darr, Dietrich (2020): Agroforestry adoption as a systems concept: A review. In *Forest Policy and Economics* 120, p. 102299. DOI: 10.1016/j.forpol.2020.102299.

Amare, Dagninet; Darr, Dietrich (2022): Farmers' intentions towards sustained agroforestry adoption: An application of the theory of planned behavior. In *Journal of Sustainable Forestry*. DOI: 10.1080/10549811.2022.2123358.

Amare, Dagninet; Mekuria, Wolde; Belay, Beyene (2017): Willingness and Participation of Local Communities to Manage Communal Grazing Lands in the Lake Tana Biosphere, Ethiopia. In *Society & Natural Resources* 30 (6), pp. 674–689. DOI: 10.1080/08941920.2016.1264649.

Amare, Dagninet; Mekuria, Wolde; T/wold, Tilaye; Belay, Beyene; Teshome, Akalu; Yitaferu, Birru et al. (2016): Perception of local community and the willingness to pay to restore church forests: the case of Dera district, northwestern Ethiopia. In *Forests, Trees and Livelihoods* 25 (3), pp. 173–186. DOI: 10.1080/14728028.2015.1133330.

Amare, Dagninet; Wondie, Menale; Mekuria, Wolde; Darr, Dietrich (2019): Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. In *Small-scale Forestry* 18 (1), pp. 39–56. DOI: 10.1007/s11842-018-9405-6.

Assaad, Ragui; Krafft, Caroline; Yassin, Shaimaa (2018): Comparing retrospective and panel data collection methods to assess labor market dynamics. In *IZA J Develop Migration* 8 (1). DOI: 10.1186/s40176-018-0125-7.

Barrett, C.B; Reardon, T.; Webb, P. (2001): Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. In *Food Policy* 26 (4), pp. 315–331. DOI: 10.1016/S0306-9192(01)00014-8.

CSA (2022): Population of Woredas as of July 2021. Central Statistics Authority (CSA). Addis Abeba. Available online at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.statsethiopia.gov.et/wp-content/uploads/2020/08/Population-of-Weredas-as-of-July-2021.pdf.

Dessie, Abebe Birara; Abtew, Asmamaw Alemu; Koye, Abebe Dagnew (2019): Determinants of the production and commercial values of Eucalyptus woodlot products in Wogera District, Northern Ethiopia. In *Environ Syst Res* 8 (1). DOI: 10.1186/s40068-019-0132-6.

FAO (2020): Agroforestry:Definition. Available online at http://www.fao.org/forestry/agroforestry/80338/en/, checked on 8/7/2020.

Feder, Gershon; Umali, Dina L. (1993): The adoption of agricultural innovations. In *Technological Forecasting and Social Change* 43 (3-4), pp. 215–239. DOI: 10.1016/0040-1625(93)90053-A.

Fischer, Elisabeth; Qaim, Matin (2012): Linking Smallholders to Markets: Determinants and Impacts of Farmer Collective Action in Kenya. In *World Development* 40 (6), pp. 1255–1268. DOI: 10.1016/j.worlddev.2011.11.018.

Glover, Dominic; Sumberg, James; Andersson, Jens A. (2016): The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. In *Outlook Agric* 45 (1), pp. 3–6. DOI: 10.5367/oa.2016.0235.

Hoffman, Voker (2007): Book Review. In *The Journal of Agricultural Education and Extension* 13 (2), pp. 147–158. DOI: 10.1080/13892240701289601.

Jamala, G. Y.; Shehu, H. E.; Yidau, J. J.; Joel, L. (2013): Factors Influencing Adoption of Agro-Forestry among Smallholder Farmers in Toungo, Southeastern, Adamawa State, Nigeria. In *IOSR-JESTFT* 6 (6), pp. 66–72.

Jerneck, Anne; Olsson, Lennart (2013): More than trees! Understanding the agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya. In *Journal of Rural Studies* 32, pp. 114–125. DOI: 10.1016/j.jrurstud.2013.04.004.

Kiptot, E.; Franzel, S. (2011): Gender and agroforestry in Africa: are women participating? ICRAF Occasional Paper No. 13.

Leonard, Madeleine (2004): Bonding and Bridging Social Capital: Reflections from Belfast. In *Sociology* 38 (5), pp. 927–944. DOI: 10.1177/0038038504047176.

Lubell, Mark; Niles, Meredith; Hoffman, Matthew (2014): Extension 3.0: Managing Agricultural Knowledge Systems in the Network Age. In *Society & Natural Resources* 27 (10), pp. 1089–1103. DOI: 10.1080/08941920.2014.933496.

Marenya, Paswel P.; Barrett, Christopher B. (2007): Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. In *Food Policy* 32 (4), pp. 515–536. DOI: 10.1016/j.foodpol.2006.10.002.

Meijer, Seline S.; Catacutan, Delia; Ajayi, Oluyede C.; Sileshi, Gudeta W.; Nieuwenhuis, Maarten (2015): The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. In *International Journal of Agricultural Sustainability* 13 (1), pp. 40–54. DOI: 10.1080/14735903.2014.912493.

Mekuria, Wolde; Getnet, Kindie; Yami, Mastewal; Langan, Simon; Amare, Dagninet (2021): Perception of communities when managing exclosures as common pool resources in northwestern Ethiopia. In *Land Degrad Dev* 32 (1), pp. 35–48. DOI: 10.1002/ldr.3689.

Mercer, D. E. (2004): Adoption of agroforestry innovations in the tropics: A review. In *Agroforestry Systems* 61-62 (1-3), pp. 311–328. DOI: 10.1023/B:AGFO.0000029007.85754.70.

Mercer, D. E.; Miller, R. P. (1998): Socioeconomic research in agroforestry: progress, prospects, priorities. In P. K. R. Nair, C. R. Latt (Eds.): Directions in Tropical Agroforestry Research, vol. 53. Dordrecht: Springer Netherlands (Forestry Sciences), pp. 177–193.

Mutambara, J.; Dube, I. V.; Mvumi, B. M. (2012): Agroforestry technologies involving fodder production and implication on livelihood of smallholder livestock farmers in Zimbabwe. A case study of Goromonzi District. In *Livestock Research for Rural Development* 24 (11).

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Nohmi, Makoto; Tsubo, Mitsuru et al. (2017): Factors Affecting Small-Scale Farmers' Land Allocation and Tree Density Decisions in an Acacia decurrens-Based taungya System in Fagita Lekoma District, North-Western Ethiopia. In *Small-scale Forestry* 16 (2), pp. 219–233. DOI: 10.1007/s11842-016-9352-z.

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Tsubo, Mitsuru; Ayalew, Zemen; Abele, Steffen (2020): Economic and financial sustainability of an Acacia decurrens-based Taungya system for farmers in the Upper Blue Nile Basin, Ethiopia. In *Land Use Policy* 90, p. 104331. DOI: 10.1016/j.landusepol.2019.104331.

Oca Munguia, Oscar Montes; Llewellyn, Rick (2020): The Adopters versus the Technology: Which Matters More when Predicting or Explaining Adoption? In *Applied Economic Perspectives and Policy* 42 (1), pp. 80–91. DOI: 10.1002/aepp.13007.

Pattanayak, Subhrendu K.; Evan Mercer, D.; Sills, Erin; Yang, Jui-Chen (2003): Taking stock of Agroforestry adoption studies. In *Agroforestry Systems* 57 (3), pp. 173–186. DOI: 10.1023/A:1024809108210.

Rogers, E. M. (2003): Diffusion of Innovations. New York: Free Press.

Russell, D.; Franzel, S. (2004): Trees of prosperity: Agroforestry, markets and the African smallholder. In *Agroforestry Systems* 61-62 (1-3), pp. 345–355. DOI: 10.1023/B:AGFO.0000029009.53337.33.

Sanginga, Pascal C.; Kamugisha, Rick N.; Martin, Adrienne M. (2007): Conflicts management, social capital and adoption of agroforestry technologies: empirical findings from the highlands of southwestern Uganda. In *Agroforestry Systems* 69 (1), pp. 67–76. DOI: 10.1007/s10457-006-9018-5.

Schiller, Katharina J.F.; Klerkx, Laurens; Poortvliet, P. Marijn; Godek, Wendy (2020): Exploring barriers to the agroecological transition in Nicaragua: A Technological Innovation Systems Approach. In *Agroecology and Sustainable Food Systems* 44 (1), pp. 88–132. DOI: 10.1080/21683565.2019.1602097.

Smith, Mark Stafford; Mbow, Cheikh (2014): Editorial overview: Sustainability challenges: Agroforestry from the past into the future. In *Current Opinion in Environmental Sustainability* 6, pp. 134–137. DOI: 10.1016/j.cosust.2013.11.017.

Soete, L.; Verspagen, B.; TerWeel, B. (2010): Systems of innovation. In B. H. Hall, N. Rosenberg (Eds.): Economics of innovation, Handbooks in Economics, vol. 2. Amsterdam.

Sood, K. K.; Najiar, C.; Singh, K. A.; Handique, P.; Singh, B.; Rethy, P. (2008): Association between socio-economic parameters and agroforestry uptake: evidences from eastern Himalaya. In *Indian J. For* 31 (4), pp. 559–564.

Tow, Philip; Cooper, Ian; Partridge, Ian; Birch, Colin (2011): Rainfed Farming Systems. Dordrecht: Springer Netherlands.

Vignola, Raffaele; Harvey, Celia Alice; Bautista-Solis, Pavel; Avelino, Jacques; Rapidel, Bruno; Donatti, Camila; Martinez, Ruth (2015): Ecosystem-based adaptation for smallholder farmers: Definitions, opportunities and constraints. In *Agriculture, Ecosystems & Environment* 211, pp. 126–132. DOI: 10.1016/j.agee.2015.05.013.

Wikipedia (2020): Amhara Region. Wikipedia: The Free Encyclopedia. Available online at https://en.wikipedia.org/wiki/Amhara_Region.

Wondie, Menale; Mekuria, Wolde (2018): Planting of Acacia decurrens and Dynamics of Land Cover Change in Fagita Lekoma District in the Northwestern Highlands of Ethiopia. In *Mountain Research and Development* 38 (3), pp. 230–239. DOI: 10.1659/MRD-JOURNAL-D-16-00082.1.

World Bank (2020): Ethiopia—Sustainable Land Management Project I and II. Independent Evaluation Group, Project Performance Assessment Report. World Bank. Washington, DC (153559).

World Bank (2022): World Development Indicators.

Wydra, Sven (2015): Challenges for technology diffusion policy to achieve socio-economic goals. In *Technology in Society* 41, pp. 76–90. DOI: 10.1016/j.techsoc.2014.12.002.

Zerihun, Mulatu Fekadu (2020): Institutional Analysis of Adoption of Agroforestry Practices in the Eastern Cape Province of South Africa. In *SAJEE* 36. DOI: 10.4314/sajee.v36i1.9.

Zerihun, Mulatu Fekadu; Muchie, Mammo; Worku, Zeleke (2014): Determinants of agroforestry technology adoption in Eastern Cape Province, South Africa. In *Development Studies Research* 1 (1), pp. 382–394. DOI: 10.1080/21665095.2014.977454.

### 4.3. Farmers' intentions towards sustained agroforestry adoption: an application of the theory of planned behavior

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**Abstract**

Adoption of AF, which is a combination of growing perennial trees and crops and/ or livestock in spatial and temporal arrangements, is recommended to improve smallholders' livelihoods. Similar to several other technologies, the adoption status of AFI in SSA is considered poor. Studies have shown that a plethora of biophysical and socioeconomic variables affect the adoption of agroforestry innovations. In these studies, psychological variables' contribution to voluntary decision-making on AF adoption decisions is often neglected and marginally explored. This paper explores the role of psychological variables in sustained AF adoption intention. We employed the Theory of Planned Behavior (TPB) to predict the sustained AF adoption intentions of 327 farmers in the Amhara region of Ethiopia. The confirmatory factor analysis assesses the intention for sustained agroforestry woodlots adoption. Farmers' intention to sustain the adoption of AF woodlot innovations is driven principally by their positive evaluation of the cash and livelihood benefits of the innovations (attitude) compared to traditional farming, their capability to produce the innovations, and the accessibility of resources (perceived behavioral control), and the farmers' perception of pressure and expectations from experts and important others (subjective norms). By employing TPB, this study brings a theoretical contribution to the TPB framework and measurement guidelines, unveils limitations of applying confirmatory factor analysis in a 'new' (woodlots) context, and suggests data based policy and development implications.

Keywords: Attitude, subjective norms, perceived behavioral control, AF woodlots, CFA

**Introduction**

Adopting agricultural innovations (i.e., knowledge, practices, and technologies) is critical to improving livelihoods and catalyzing structural change in African agriculture. The importance of AFI to smallholder farmers cannot be overestimated in SSA due to its many benefits. It immensely contributes to improving food security (Mbow et al. 2014) and livelihoods diversification (Tittonell 2014), climate change adaptation (Vignola et al. 2015), and sustainable natural resources management (Coe et al. 2014; Smith and Mbow 2014). AF is a land-use system in which woody perennials are deliberately integrated into land management with agricultural crops and/or animals in some spatial arrangement or temporal sequence (FAO 2020).

AF is a traditional practice in SSA as farmers continuously retain trees on farms (Amare et al. 2019) and grazing lands (Endale 2019), establish home gardens (Bantihun and Abera 2019), plant shade trees (Belay et al. 2019) and woodlots (Nigussie et al. 2017). In addition to these traditional practices, a large variety of modern AFI have been introduced by extension services, donor projects etc. in the context of rural development and environmental rehabilitation programs and policies (Ajayi et al. 2011). Nevertheless, the adoption of these AFI remains low for a variety of reasons (Partey et al 2017; Mercer 2004). Along with the absence of a pluralistic extension system that addresses the dissimilar needs of various target groups (Mbow et al. 2014; Lubell et al. 2014), low dissemination of AFI in SSA has also been ascribed to the marginal uptake of the results from AF adoption studies by development practitioners (Glover et al. 2016).

Psychological factors are important components of farmers' decision contexts as they represent their motivation to make adoption decisions based on voluntary action (Sok et al 2020). This is true as farmers might ignore adoption mainly due to nonalignment of the innovations to their customs and norms (Buyinza et al 2020). Hence, psychological variables, i.e. the set of overt actions performed by an individual (Kan and Fabrigar 2017; Ajzen 2011), are important for making AF adoption decisions. Meijer et al. (2015a) already suggested focusing more on such psychological factors labelled as intrinsic factors. In addition, a meta-analysis of 58 AFI adoption studies (Amare and Darr 2020) revealed that psychological factors, notwithstanding their infrequent use in econometric models, were a better predictor of AF adoption than the commonly used demographic variables. We also presume that exploring psychological factors beyond the dominant expected utility models enhances our understanding of farmers' decision-making contexts.

Most previous studies exploring the adoption of innovations, however, generally ignore the underlying psychological constructs that affect farmers' decision making behaviors (Borges et al. 2014). Despite the fact that previous studies have used a variety of research approaches such as case studies, qualitative narrations, econometric modelling or a combination of them, this methodological diversity has not (yet) facilitated a broader view on the determinants of adoption. Regardless the general suitability of qualitative research to investigate the relevant psychological states, most studies found that bio-physical, socioeconomic characteristics and system-level features are main determinants of smallholders' decision making factors on whether or not to adopt AFI (Amare and Darr 2020). With the exception of few notable studies (Meijer et al. 2015b; Borremans et al. 2016; Sereke et al. 2016; Zubair and Garforth 2006; Hussain et al. 2012; Buyinza et al. 2020), the contribution of psychological factors to making AF adoption decisions or intentions remains less explored. A review article also indicated the marginal presence of studies relating to farmer decision making behavior in forestry context (Sok et al. 2021). In the current paper, we therefore evaluate the importance of these variables to more clearly discern their impact on the adoption intention of selected AFI. In light of the strong influence that psychological factors have on AF adoption decisions (Amare and Darr 2020; Buyinza et al. 2020) and earlier calls for research on these aspects (Meijer et al. 2015a), our work contributes to closing a remaining gap in the literature on the effects of psychological factors on smallholder AF woodlots adoption intentions. These intentions to voluntary continue adoption of AF woodlots are mainly shaped by attitudes, subjective norms and perceived behavioral control according to the theory of planned behavior (TPB) (Ajzen 1991). We therefore employ this theory to investigate our research question.

While psychological factors were rarely in the focus of a few AF adoption studies, none of these studies explicitly focused on AF woodlots. Woodlots represent a rich AF system, in regards to crop-livestock species composition, where the AF species are inter-cropped with selected crops at early stages of plantation, and later either livestock is left to graze between the AF trees or the grass is harvested for livestock feed (Nigussie et al. 2020). These AF systems often are a cash-focused commercial activity (Dessie et al. 2019), involve bigger investments (Nigussie et al. 2020; Nigussie et al. 2017), create larger economic and environmental impact (Kebebew and Ayele 2010), and are associated with higher risks (Dessie et al. 2019; Yitaferu et al. 2013) compared to the more common AFI that were the focus of the above studies. In addition to the necessity to conduct more studies on farmers' AF adoption decision-making in general, studies focusing on AF woodlots are hence particularly needed to broaden the conceptual basis beyond the often-researched traditional small-scale AF practices. Subsequently, this study also aims to uncover the effect of psychological variables on adoption intention of farmers specifically for AF woodlots by explicitly exploring the farmers' positive or negative evaluation towards the AFI (attitude), the perceived expectations from significant others placed on the farmer (subjective norms), and the individuals perceived ability to enact the AF adoption behavior (perceived behavioral control) as narrated by Ajzen (2011; 2001).

Whereas much of previous adoption research has focused on factors explaining the farmers' initial adoption decision behaviors (Buyinza et al. 2021), we are particularly interested in understanding the determinants of the intentions to sustain (continue) AF adoption beyond current behavior. As such, our study can reveal factors relevant for discontinuation decisions or intentions, an area so far underrepresented in the literature. We investigate sustained adoption intention through three distinct dimensions; namely, the intention to maintain (i.e., to continue the current AF practice, both in management and intensity), to modify (i.e., change the current management practices, such as row spacing, seed rate or fertilization) or to expand (i.e., to increase the intensity or size of current adoption) the AFI practice. Collectively, we label these three dimensions the 'intention to sustained adoption'. Comprehending these dimensions, from an innovations adoption perspective, helps to reinforce successful implementation of future interventions aimed at sustaining (agro)forestry development.

Finally, we aim to explore if the parsimonious TPB framework is sufficient to predict the farmers' intention to adopt AF woodlots. This is a question of ongoing debate given that various extensions of the TPB were proposed in the past aiming to increase its validity and predictive power by incorporating further variables into the framework (e.g., Leeuw et al. 2015; Sok et al. 2021). This notwithstanding, the sufficiency assumption postulates that the original TPB framework comprising the three constructs attitude, subjective norms and perceived behavioral control is sufficient to correctly predict an individual's intention (Ajzen 2020, 2022). We investigate these questions focusing on the adoption of three different AF woodlot innovations in the highlands of Ethiopia. Overall, we aim to make a useful contribution to the adoption literature, as well as to development practice and the sustainability transition of food systems in the global South.

**Theoretical framework and hypotheses**

Refined from the theory of reasoned action (TRA, Fishbein and Ajzen 2011), TPB is a major theoretical framework frequently employed to explain and predict human behavior (Ajzen 2020, 1991, 2011). TPB is preferred and suggested by several authors (e.g., Godin and Kok 1996) over TRA which excludes perceived behavioral control (Ajzen 2022). The theory focuses on an individual's conscious decision-making and on behaviors that are goal-oriented (Sok et al. 2021). The TPB (Fig.1) narrates that intentions, as immediate antecedents of behavior (Ajzen 2020), can be predicted with high accuracy from (1) attitudes toward the behavior (i.e., the polarized, negative or positive, views and opinions towards a particular behavior), (2) subjective norms (i.e., perceived pressure from significant others towards engagement in the behavior), and (3) perceived behavioral control (i.e., the perceived own capability to successfully implement the behavior).

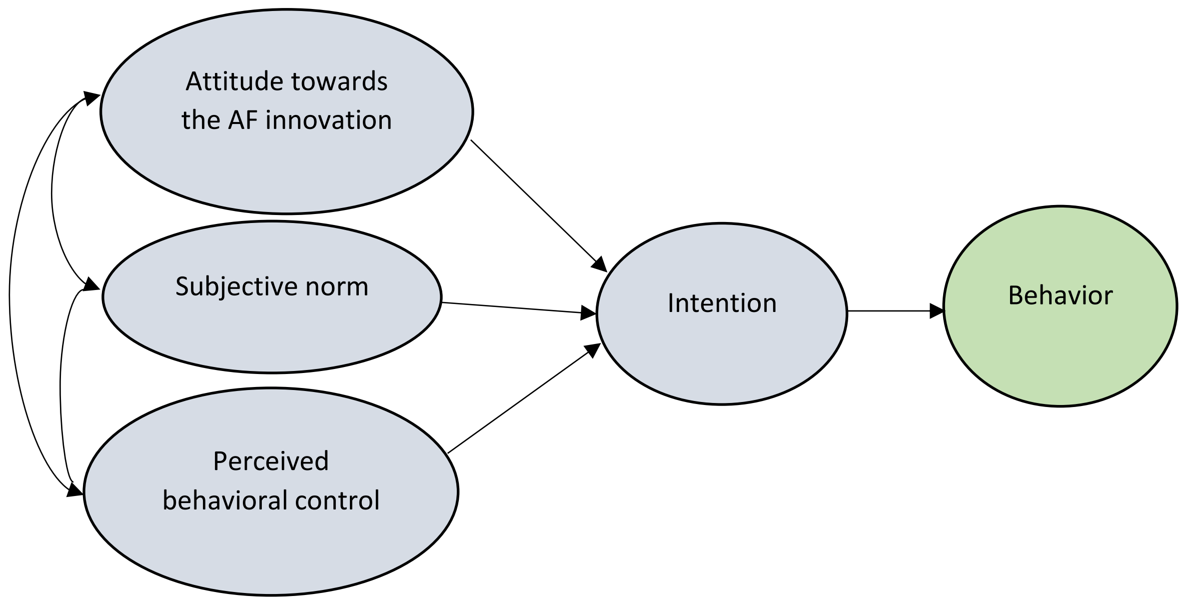


Figure 1. Theory of planned behavior (Adapted from Ajzen 2022)

These intentions, together with perceptions of behavioral control, account for considerable variance in actual behavior (Ajzen 1991, 2011). A meta-analysis (Armitage and Conner 2001) confirmed that these psychological variables account for 39% and 27% of the variance for intentions and actual behavior of individuals, respectively. TPB has been widely applied among others in health sciences (Hirschey et al. 2020), social and behavioral sciences (Davis et al. 2015), agricultural sciences (Sok et al. 2021; Buyinza et al. 2020; Borges et al. 2019), for assessing pro-environmental (Leeuw et al. 2015), recycling (Chan and Bishop 2013; Kaiser et al. 2005), and food choice behaviors (McDermott et al. 2015), and opinions on natural park conservation (López-Mosquera 2016).

Despite the fact that the theory has been empirically validated in various settings (Fielding et al. 2008), authors continue to expose the TPB to further empirical tests in order to extend its range or to seek further improvements of its explanatory power (Sok et al. 2021). This is mainly achieved by inclusion of additional constructs such as moral norms (Leeuw et al. 2015; López-Mosquera 2016), self-identify (Sok et al. 2021), group norm and uncertainty (Borremans et al. 2016) and ecosystem services (Sereke et al. 2016) among others. While the potential for extending the TPB remains supported even by Ajzen (2020), the inclusion of further constructs needs to be justified by an improved predictive power of the model vis-à-vis the original model (Sok et al. 2021). Authors also suggested the irrelevance of extending the original TPB by adding new constructs due to lack of discriminant validity (Kaiser et al. 2005), existence of high correlation (Chan and Bishop 2013) and a decreased model fit (Leeuw et al. 2015). Therefore, while further improvement of the theory is possible and even the development of an alternative new theory instead of extending the existent framework may be useful (Sniehotta et al. 2014), the parsimonious TPB continues to be the dominating framework that by default fulfils the sufficiency assumption. In this study, we also adhere to the original TPB framework and guidelines to assess the farmers' intention to sustain adoption of AF woodlots in Ethiopia. The following hypotheses are formulated based on earlier studies (Buyinza et al. 2020; Sereke et al. 2016; Borremans et al. 2016).

H1: The attitude of farmers towards sustained AF adoption is not associated to their intention to sustain AFI adoption

> Contrary to a first-time adoption context, more information on the performance of the innovation is already available to the farmer after having practiced the innovation for some time. If more information on the performance of the innovation is available, attitudes may be less important. Hence, we hypothesize that attitudes and the intention to sustain AFI adoption are not associated.

H2: Subjective norms are positively associated to the farmers' intention to sustain AFI adoption

> Contrary to a first-time adoption context, more information on the performance of the innovation is available to the farmers' significant others, such as family, neighbors, or experts. As a result, the pressure exerted from these persons on the farmers to sustain adoption may be considerable in case the innovation is perceived as comparatively beneficial. We therefore hypothesize that the intention to sustain adoption of AFI is positively influenced by subjective norms from significant others.

H3: Perceived behavioral control is highly positively associated to the farmers' intention to sustain AF innovation adoption

Contrary to a first-time adoption context, farmers who already have successfully adopted an innovation may be more confident that they possess the required abilities and resources necessary for adoption; or alternatively may be very clear that they lack these, which will likely contribute to their intention to discontinue adoption. Hence, we propose that perceived behavioral control and the farmers' sustained AF adoption intention will have a strong positive association.

## METHODS

### *Study area*

The study was conducted in three districts of the Amhara region of Ethiopia (Figure 2). Amhara region is located in the North-western part of the country (11°39′39″N 37°57′28″E) and had a population of more than 22 million (Amare et al. 2016; CSA 2022). Mecha, Banja and Fagita Lekoma are the districts purposively selected due to the ubiquity of AF innovations and the long history of AF adoption in the region. On average, 90% of the estimated 577, 000 total population lives in rural areas primarily engaged in agricultural production for livelihoods. With elevation ranging from 1800 m asl in Mecha to 3100 m asl in Fagita Lekoma, these districts cover 223,765 ha of land and AF of different kinds is practiced extensively (Central Statistics Authority 2007; Nigussie et al. 2020; Wondie and Mekuria 2018; Tefera and Kassa 2017).

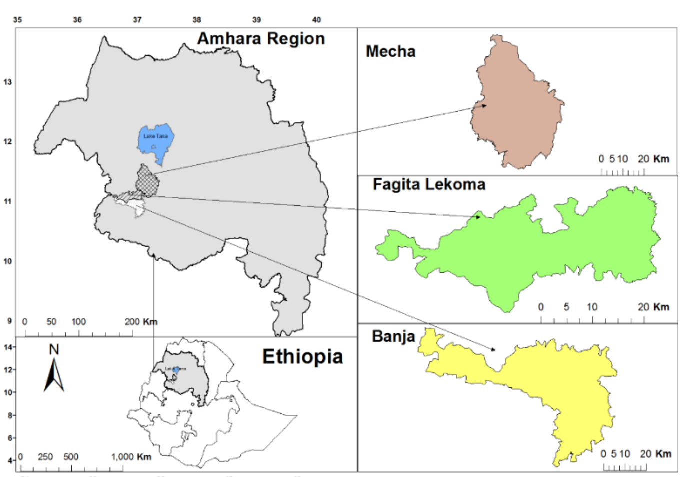


Figure 2. Study area

***The AF woodlots***

AF woodlots are currently expanding in Ethiopia and this very much is visible in Amhara region. For example, Wondie and Mekuria (2018) found on average 1.2% per annum increase of forest cover, over a period of 15 years, in Fagita district mainly due to *Acacia decurrens* plantation. Farm woodlots are increasingly common and an important form of AF for farmers to grow trees in farmlands and around homesteads in the Amhara region of Ethiopia (Abiyu et al. 2016; Amare et al. 2019). We focus in our study on woodlot innovations of *Acacia decurrens* (hereafter, acacia), *Eucalyptus camaldulensis* (hereafter, eucalyptus) and *Yushania alpine* (hereafter, bamboo), which represented the dominating AFI in the Fagita Lekoma, Mecha and Banja districts, respectively. Their dominance is ascribed to a host of factors. All of the innovations have initially been promoted by concerted government and NGO efforts in the past as rural development options, and later disseminated due to market pull and word-of-mouth dissemination among farmers based on their perceived benefits as revealed during the discussion with farmers and experts. Despite the differences in (i) the nature of innovations, and (ii) the environmental and socioeconomic conditions prevailing in the districts, this study analyzes the three innovations in aggregate because the basic psychological patterns of making the adoption decision are governed by similar factors given the homogeneous cultural and socioeconomic conditions of the smallholders. Moreover, the three practices are sufficiently adapted to the local conditions prevailing in the respective study areas.

***Salient beliefs measurement***

The questionnaire used to collect data contains both closed and open-ended questions on socioeconomic, institutional and psychological variables. To investigate salient features (items of the constructs), 5-point bipolar Likert scales (Gagne and Goding 2000) were prepared for the behavioral, normative and control beliefs correspondingly relating to attitude, subjective norms and behavioral control constructs. Questionnaire item preparation (belief elicitation) followed the TPB guidelines (Fishbein and Ajzen 2011; Ajzen 2020) by largely adapting through aggregation (i.e., combining a list of items from different studies) and extrapolation (i.e., inferring AF specific features and developing related items) of items from previous studies to the local context with input from field observations, feedback from farmers and experts and the review of literature (Sereke et al. 2016; Meijer et al. 2015b). Most items developed from local context relate to the negative and positive effects of AF production as perceived by farmers and local experts such as effects on local microclimate, land degradation and or plot fertility, local macro-economic impact including increased employment and business activities, conflicts arising between adjacent land owners due to harmful spillover or allelopathetic effects of the AFI; all forwarded as positive questions.

For sustained adoption (action) of AF woodlots innovation (target) to happen during the coming 5-10 years (time) on the respondents' farms (context) (Ajzen 2020; Sok et al. 2021), salient behavioral beliefs were elicited by asking farmers. The TPB proposes that an individual's behavior depends on the following factors, which we operationalized using the respective survey questions: (i) intention towards the behavior, which we framed in the questions: "Do you plan to maintain, modify or expand the current AF practice in the next 5-10 years?"; (ii) attitude ("What is your opinion about the output of the current AF practice?"); (iii) Perceived subjective norms ("What do you expect the reaction of stakeholders and neighbors to be?"), and (iv) perceived behavioral control of engaging in AF ("Are you confident in your abilities and resources to successfully practice the AFI?").

***Data collection***

A multi-stage sampling procedure was employed to collect data through household survey. After the districts and AFI were purposively selected, simple random sampling proportionate to sample size was used to select farmers who were practicing, or adopted at least once, the innovations under study. Data from 327 households on the three AFI was collected from March-June, 2019. Prior to the main household survey, a pretest was conducted with 18 farmers (4 female) to ensure the questions reflected actual conditions of the locality and were clearly understood. Initially, the TPB-related questions comprised 3 items for intentions (INT), 16 items for attitudes (ATT), 3 items for subjective norms (SN) and 3 items for perceived behavioral control (PBC). Information from formal and informal discussions and expert interviews from the district agricultural bureau were incorporated to substantiate results.

***Data analysis***

Descriptive statistics was used to analyze the actual responses of farmers to the respective psychological constructs. We consider Likert scores $\geq 3$ as favorable for sustained adoption and values below average (2.5) as unfavorable for the sustained adoption intention. Structural equation modeling (SEM) is employed to quantitatively assess the sustained AF adoption intention of farmers. SEM is a multivariate statistical analysis technique combining factor and multiple regression analysis to reveal structural relationships between measured variables and latent constructs (Wendorf 2002). The analysis involves the following steps: (i) reliability tests such as data screening, (ii) confirmatory factor analysis in order to obtain a satisfactory measurement model, develop and test the structural model, and (iii) goodness of fit analysis to confirm model fitness. In reliability tests, construct validity and data screening were conducted to ensure item reliability and absence of redundant items (Appendix C, Tables 1-3). Stata 14 and MS Excel 2016 are used for analysis.

***Data screening***

Multi-collinearity (Appendix C) was assessed by conducting multiple regression on the salient belief items where the districts are used as dependent variables. In the process we found that the TPB salient items didn't violate the multi-collinearity test as the tolerance values are greater than 0.1 and the average variance inflation factor (VIF) is 1.91 with no VIF value of $\geq 3$. This confirms the absence of redundancy in our model (Buyinza et al. 2020).

***Validity tests: convergent and discriminant validity***

Construct validity was evaluated by running (i) convergent validity, the extent of positive correlation between a set of indicators reflecting the same construct and (ii) discriminant validity, the extent to which each latent construct shares more variance with its indicators than any other latent construct expressed by set of different items in the model. A model fulfills a convergent validity when its composite reliability is $\geq 0.7$ and average variance extracted (AVE) is greater than 50%. Discriminant validity is achieved when the squared root of AVE is greater than the correlation between inter-construct items. A latent construct is declared valid when both convergent and discriminant validity are established (Fornell and Larcker 1981). Initially we incorporated 25 items (3 items for each INT, SN, PBC and 16 items for ATT construct). These questionnaire items, largely based on local feedback from farmers and experts, pertain to altruistic behavior (i.e., showing concern for others, in our case the community), the effects of AF woodlots production on microclimate or food production, and microeconomic effects (e.g., increased business activities, employment opportunities) were incorporated into the questionnaire. However, due to poor validity test results, only nine of the salient items were retained for further confirmatory analysis and the rest were dropped (Appendix C).

## RESULTS

### ***Summary statistics***

Eucalyptus producing farmers constitute 40.4% of the 327 sample population, while farmers with acacia and bamboo production account for 32.7% and 26.9%, respectively. Female-headed households constitute 12.8% of the population. On average farmers cultivating bamboo AF are older (50.9±1.3) than farmers producing eucalyptus (46.6±1) and acacia (43.5±1.3). Currently the farmers own on average 1.2 (±0.04) hectares of land and 3.72 (±0.1) livestock (in tropical livestock units, TLU). The farmers have been growing the three species for several years, even though the intensity of adoption and management has changed considerably during this time. Initially only a few trees or bamboo culms were planted by farmers to delineate boundaries or on grazing lands. Currently, more strategic large-scale plantations on fertile agricultural plots are increasingly common. Likewise, management changed from mere fencing without any further management to more intensive and regular activities such as composting and weeding, as revealed during the household survey.

Farmers revealed a good prospect of sustaining (3.14±0.07) the production or adoption of these AFI for the coming 5-10 years (Appendix C). With the highest average (3.71±0.06) Likert value for ATT and lowest for SN (2.94±0.7), farmers demonstrated strong intentions to sustain the AF woodlots. Smallholders' intentions to sustain AFI are to a large degree driven by the fact that they assess their capability, skills, and resources required for AF as strong and sufficient (PBC=3.44±.055). By and large, the cumulative values for the psychological constructs is the highest for acacia followed by bamboo and the lowest for eucalyptus AFI (Appendix C).

### ***Confirmatory factor analysis*** **(CFA)**

*Validation of models*

***Construct validity***: the standardized factor loadings of our constructs are all above 0.5 (Table 3). Such high loadings guarantee both construct validity and confirm that the observed indicators strongly relate to their associated constructs. Further, the model showed that the AVE for the constructs ranged from 54%-67.5% and the respective composite reliability ranged from 0.7 to 0.85 (Table 3), confirming acceptable convergent validity.

Table 1. Reliability and validity of the model

| | INT1 | INT2 | INT3 | ATT1 | ATT2 | SN1 | SN2 | PBC1 | PBC2 |
|---|---|---|---|---|---|---|---|---|---|
| **INT1** | **0.803** | | | | | | | | |
| **INT2** | 0.6823 | **0.803** | | | | | | | |
| **INT3** | 0.5713 | 0.6606 | **0.803** | | | | | | |
| **ATT1** | 0.4633 | 0.4334 | 0.4506 | **0.822** | | | | | |
| **ATT2** | 0.4262 | 0.4123 | 0.4144 | 0.6713 | **0.822** | | | | |
| **SN1** | 0.0878 | 0.1462 | 0.1487 | 0.0416 | 0.1245 | **0.816** | | | |
| **SN2** | 0.2039 | 0.2813 | 0.2579 | 0.1890 | 0.2441 | 0.5767 | **0.816** | | |
| **PBC1** | 0.3817 | 0.3543 | 0.3324 | 0.4244 | 0.3324 | 0.1358 | 0.2949 | **0.734** | |
| **PBC2** | 0.4163 | 0.2821 | 0.2590 | 0.3265 | 0.3422 | 0.0414 | 0.2332 | 0.5318 | **0.734** |

The bold diagonal values represent the discriminant validity (square root of AVE) and the lower ones are correlations between items. The correlation of SN1 is not significant with INT1, ATT1 and PBC2; all the other correlations are significantly correlated.

Additionally, the squared AVE values (ranging from 0.734 to 0.803) were higher than the inter-construct correlations (0.042 to 0.68), confirming discriminant validity criteria. As our validity tests proved the fulfilment of construct validity, we further explore reliability tests. Table 1 shows that the inter-item correlations are lower than the respective discriminant validity values. Our measurement model hence is reliable for further (structural) confirmatory factor analysis.

In regards to model fit, the coefficient of determination, which shows the R-squared of the whole model, proved the model fit. With 90% confidence interval, the RMSEA is also a close fit as the lower bound (0.037) is well below 0.05 and the upper bound (0.084) is below 0.1. Overall goodness of fit (Table 2) proves that psychological factors can be used to predict the farmers' behavioral intentions to sustain AF woodlots adoption in the study region.

Table 2. Overall model fitness

| Static | Threshold | Model result* | Meaning of static |
|---|---|---|---|
| **TLI** | ≥ 0.900 | 0.961 | Tucker Lewis Index |
| **CFI** | ≥ 0.900 | 0.977 | Comparative fit index |
| **RMSEA** | ≤ 0.08 | 0.061 | Root mean square error of approximation |
| **PCLOSE** | ≥ 0.05 | 0.212 | Probability RMSEA <= 0.05 |
| **SRMR** | 0-0.08 | 0.031 | Standardized root mean squared residual |
| **CD** | ≈1.000 | 1.000 | Coefficient of determination |

*The model result is for both measurement and structural models

### *Measurement model*

The standardized loadings for the measurement model are listed below (Table 3). Cronbach's alpha is a statistic frequently employed to indicate the reliability (or internal consistency) of a number of items that supposedly form a scale. Our Cronbach's alpha indicated that our salient items fulfill the scale reliability. Overall, our analysis indicated a valid measurement model.

Table 3. The standardized factor loadings for each salient item with standard errors in bracket, and the AVE, composite reliability (CR) and the scale reliability coefficient (Cronbach's alpha) for each construct of the measurement model

| | Intention | | **ATT** | | **PBC** | | **SN** | |
|---|---|---|---|---|---|---|---|---|
| | INT1 | 0.81 (0.03) | ATT1 | 0.86 (0.03) | PBC1 | 0.79 (0.05) | SN1 | 0.58 (0.06) |
| | INT2 | 0.84 (0.03) | ATT2 | 0.78 (0.04) | PBC2 | 0.67 (0.05) | SN2 | 1 (0.09) |
| | INT3 | 0.76 (0.03) | | | | | | |
| | | | | | | | | |
| **AVE (%)** | 64.47 | | 67.52 | | 53.83 | | 66.66 | |
| **CR** | 0.845 | | 0.806 | | 0.699 | | 0.789 | |
| **alpha** | 0.841 | | 0.803 | | 0.692 | | 0.729 | |

SEM Maximum likelihood method; LR test of model vs. saturated: $\chi^2(21) = 46.18$, Prob > $\chi^2 = 0.0012$; all items are significantly at p=0.000.

### *Structural model*

The results of the structural model showed that all the three constructs of the parsimonious TPB framework are significantly correlated to the sustained AF woodlots adoption intention of farmers (Table 4). The standardized coefficient shows that polarized feelings of a farmer (ATT) are significantly and highly correlated to sustained AF woodlots adoption. Our hypothesis (H1) that attitude is not correlated to adoption decision must therefore be rejected. A positively significant association of PBC to sustained AF adoption confirms hypothesis 2 (H2), which claimed that perceived ability is significantly associated to sustained adoption of AF innovations.

Table 4. Structural model

| **Relationship** | **Standardized coefficient** | **p-value** | **Hypothesis** | **Decision** |
|---|---|---|---|---|
| **ATT –> Intention** | 0.48 (0.073) | 0.000 | H1:not significant | Reject |
| **PBC –> Intention** | 0.25 (0.085) | 0.004 | H2:positively significant | Accept |
| **SN –> Intention** | 0.10 (0.056) | 0.075 | H3:positively significant | Accept |

Ultimately, positive and significant correlation of SN to intention proves our hypothesis (H3) on the significant effect that pressure from significant others has on the sustained adoption intention of farmers. Overall, ATT showed the strongest coefficient and significance followed by PBC. In regards to SN, the coefficient is relatively small and its significance is limited to 10% level of significance indicating high volatility of significance and non-significance for alternative contexts such as farming conditions or markets.

The model also showed ATT and PBC have the highest covariance (0.594) followed by SN vs. PBC (0.353). ATT and SN also co-vary by a factor of 0.25. Hence, a farmer's own positive or negative feelings about the AF innovation and own capability to produce go together. When farmers perceive the AF innovations positively, there is high likelihood that they also believe or possess the skills and resources to produce them, or vice-versa. Similarly, when farmers feel that significant others are pushing them to produce the AF innovations, farmers perceive their skills (capabilities) and resources to produce more favorably. But significant others have minimal influence when farmers have positive perception about the innovations. The possession of positive view about the innovation and the degree to which significant others motivate to produce are slightly positively linked.

**Discussion**

This study, to the best of our knowledge, is the first of its kind where the TPB is used to explore the effect of psychological constructs on farmers' long-term AF woodlots adoption intention. Results of the measurement model (Table 3) showed that behavioral, normative and control beliefs drive the intention of sustained adoption. The structural model (Table 4) also showed that attitudes, subjective norms and perceived behavioral control are significantly correlated to intention to sustained adoption.

In general, our study only partially supported previous studies and our hypotheses. This holds particularly for the relationship between the farmers' intention to adopt and subjective norms given that the literature on this relationship is inconclusive. Contrary to our results, Buyinza et al. (2020) did not find a significant association of subjective norms to adoption intention to integrate trees in coffee plantations. Likewise, Fielding et al. (2008) and (Meijer et al. 2015b) stated that subjective norms make no or only a weak contribution to adoption intentions. Paradoxically, Borges et al. (2019) indicated largely (eleven times out of twelve executions) significant relationship between intention for adoption of agricultural innovations and subjective norms. Our study results are more in congruence with the findings of Hussain et al. (2012), who also investigated a smallholder context, and studies that investigated the commercialized farming sector in Europe (Borremans et al. 2016; Sereke et al. 2016). This can be attributed to the difference in our approach of exploring long-term adoption behavior in contrast to first time adoption of AF. Contrary to other studies, in our study farmers already have the experience, and significant others (e.g., neighbors, experts, family) have already experienced the benefits of these AF woodlots in light of existing market opportunities. Farmers in our study areas hence tend to be influenced by their significant others to sustain adoption of these AF innovations.

Also, contrary to our hypothesis, we found that attitude is highly and significantly correlated to sustained adoption. This is in line with Buyinza et al. (2020) who found that attitude is significantly correlated to smallholder intention to integrate trees in coffee plantations in a first time adoption context. While contrary to our hypothesis, this significant relationship is also in line with the general TPB. In fact, we found that farmers' positive evaluation of the benefits of AF woodlots is the main factor affecting sustained adoption intention. Meijer et al. (2015b) found significantly more positive attitude for tree planting from farmers who planted AF compared to those who never planted AF in the past 5 years. A review (Borges et al. 2019) revealed a positive significant correlation of attitude and agricultural innovations adoption intention, whereas a single analysis revealed a negative correlation of both variables.

Similarly, perceived behavioral control is significantly correlated to the sustained adoption intention. This result is in congruence with Buyinza et al. (2020) who found that PBC is significantly associated to the farmers' intention to integrate trees in their coffee farms. The positive belief of farmers in their capability to efficiently plant and manage AF innovation reinforces their intention to adopt. The AFI in our study only require marginal management such as weeding, fertilization or manuring in the first year. Afterwards the woodlots do not receive management inputs apart from fencing to protect the trees from animal and human damage. In this context the perceived behavioral control values may be relatively high given that no specific skills are required that would go beyond the farmers' regular farming skills. However, in case more sophisticated AF innovations are concerned that require specific skills and resources, the farmers' PBC might be much lower, and the association between intention and PBC might be lower or even negatively associated, or no-association at all. Generally, the dependence of smallholders on tacit and indigenous knowledge for managing AF trees is also recounted (Ofoegbu and Ifejika Speranza 2017). Meijer et al. (2015b) found more positive PBC for tree planting from farmers who adopted

AF in the past 5 years compared to those with no experience of AF adoption in the previous five years. In their review, Borges et al. (2019) found a more balanced result of five positive and four negative associations of AF adoption intention with perceived behavioral control.

Overall, all the three constructs are significantly correlated to sustained adoption intention of smallholder farmers. Attitude followed by perceived behavioral control and subjective norms regulate farmers' behavioral intentions for sustained AF adoption. The coefficient of determination (Table 3) also revealed high explanation of the smallholders' adoption intention. The exclusion of salient items from the confirmatory factor analysis due to poor validity results, and the overall model fit proved that the parsimonious TPB framework is sufficient for predicting the farmers' behavioral intentions to sustained adoption of AF woodlot innovations.

***Limitations and implications for future research***

During model development, we also encountered non-convergence of the model, amid all model fitness results (Table 1,2,3). Non-convergence might lead to a negligible change in the coefficients of the respective constructs as shown by the continued extremely inconsiderable change in the value of log likelihood, as the iterations increased. Yet, the model is considered and interpreted valid by all accounts as the (i) sample size is large enough (>200) for SEM analysis, (ii) all validity tests proved worthiness of the model (Table 1,2,3), and (iii) multi-collinearity is not an issue (Supp. Table 1) amid a possibility of accepting some level of multi-collinearity in TPB analysis (StataCorp. 2013; Sok et al. 2021). We however attributed this shortcoming to the measurement error associated to the design of our salient items. First, we used 5-point Likert scale instead of the widely employed 7-point Likert scale. The use of a 5-point scale (amid reliable scaling, Table 3) might have reduced the robustness of our SEM analysis vis-à-vis the more preferred 7-point scales (Gagne and Goding 2000). Secondly, most of the salient items were initially aggregated in order to incorporate local context questions and reduce the overall number of questions to avoid interviewee fatigue and poor response. For example, we framed one of the questions related to elicit subjective norms as "Significant others (i.e., siblings, local leaders and government officers) expect me to produce this AF to improve my livelihoods". Breaking this question into separate questions for each type of significant others would have provided more granular results. Future AF adoption studies aiming to use the salient items should further improve the behavioral, normative and control items.

**Conclusion and implications**

In the context of high demand for a more robust understanding of farmers' decision making behavior, this study explored the importance of psychological constructs to making sustained adoption of AF woodlots. By doing so, we have confirmed that, psychological constructs are important factors for making adoption decisions, thereby rebutting the assumption inherent in most studies that predominantly employ conventional socioeconomic variables in adoption research.

We also proved that the TPB better predicts farmer behavior compared to reasoned action theory (TRA) as the perceived behavioral control construct (which is not included in TRA) is found significantly associated to sustained AF woodlots adoption intention. In general, the farmers' positive perception of the AF woodlots doesn't readily lead to sustained adoption, although it is highly strongly correlated to adoption intention. Continued adoption is influenced or mediated by the perceived possession of skills and land resources and, to some lesser extent, the pressure exerted by significant others. In our study farmers have a favorable intention to sustain adoption of the AF woodlots. Government and affiliated organizations are thus encouraged to support this intention by facilitating market access for the AF woodlots products. Further, designing policies that assist farmers to realize the benefits associated with AF despite the time-lag between AF establishment and its full production, or despite poor or unstable market demand is essential. Improving farmers' bargaining power and introducing various product processing innovations that increase market demand for the products are other means to encourage farmers' AF adoption intention. Provision of technical advice and trainings will help to propel the farmers' perceived behavioral control and hence reinforce their positive attitude, which further strengthens their intention to adopt. Farmers showed that they are more likely to sustain AF woodlots adoption if subjective norms are conducive. To create strong subjective norms that reinforce their perceived behavioral control and positive attitude local development agents should possess and provide better skills and knowledge on AF woodlots production, as the propensity of influencing a farmer is highly related to their perceived skillfulness or contribution of individuals among others. Significant others such as siblings and peers or neighbors should be encouraged to provide credit and shared labor for planation and management to reinforce or capitalize their effect on sustained adoption intention of farmers. Business organizations, as one of the significant others, should tailor updated information on price, demand for woodlot products and new market opportunities in order these farmers actualize their adoption intention through the influence of significant others.

Most of the initially incorporated questionnaire items, largely relating to altruistic behavior, are excluded from the final confirmatory factor analysis due to poor reliability results. Consequently, we conclude that the parsimonious TPB model is sufficient to predict the intention of farmers and its extension in the context of exploring AF woodlots sustained adoption is irrelevant.

Consequently, researchers should enquire the psychological perspectives of adoption decisions, whether in AF or agriculture in general, in order to disentangle the entire decision contexts in this regard. Finally, future studies aiming at revealing the influence of psychological constructs on AF adoption decisions should not directly employ the items used in this study due to the convergence issue encountered. Instead we strongly recommend they avoid aggregation of items and rather suggest development of specific questions for each salient belief item and stakeholder or significant others. Additionally, we propose the use of 7-point Likert scale instead of the 5-point or less scale Likert measurements.

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**Supplementary file:** Appendix C

## Publication bibliography

Abiyu, Abrham; Teketay, Demel; Gratzer, Georg; Shete, Maru (2016): Tree Planting by Smallholder Farmers in the Upper Catchment of Lake Tana Watershed, Northwest Ethiopia. In *Small-scale Forestry* 15 (2), pp. 199–212. DOI: 10.1007/s11842-015-9317-7.

Ajayi, Oluyede Clifford; Place, Frank; Akinnifesi, Festus Kehinde; Sileshi, Gudeta Weldsesemayat (2011): Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). In *International Journal of Agricultural Sustainability* 9 (1), pp. 129–136. DOI: 10.3763/ijas.2010.0554.

Ajzen, Icek (1991): The theory of planned behavior. In *Organizational Behavior and Human Decision Processes* 50 (2), pp. 179–211. DOI: 10.1016/0749-5978(91)90020-T.

Ajzen, Icek (2001): Nature and operation of attitudes. In *Annual review of psychology* 52, pp. 27–58. DOI: 10.1146/annurev.psych.52.1.27.

Ajzen, Icek (2011): The theory of planned behavior: reactions and reflections. In *Psychology & health* 26 (9), pp. 1113–1127. DOI: 10.1080/08870446.2011.613995.

Ajzen, Icek (2020): The theory of planned behavior: Frequently asked questions. In *Human Behav and Emerg Tech* 2 (4), pp. 314–324. DOI: 10.1002/hbe2.195.

Ajzen, Icek (2022): Theory of Planned Behavior; FAQs. Available online at https://people.umass.edu/aizen/faq.html.

Amare, Dagninet; Darr, Dietrich (2020): Agroforestry adoption as a systems concept: A review. In *Forest Policy and Economics* 120, p. 102299. DOI: 10.1016/j.forpol.2020.102299.

Amare, Dagninet; Mekuria, Wolde; T/wold, Tilaye; Belay, Beyene; Teshome, Akalu; Yitaferu, Birru et al. (2016): Perception of local community and the willingness to pay to restore church forests: the case of Dera district, northwestern Ethiopia. In *Forests, Trees and Livelihoods* 25 (3), pp. 173–186. DOI: 10.1080/14728028.2015.1133330.

Amare, Dagninet; Wondie, Menale; Mekuria, Wolde; Darr, Dietrich (2019): Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. In *Small-scale Forestry* 18 (1), pp. 39–56. DOI: 10.1007/s11842-018-9405-6.

Armitage, C. J.; Conner, M. (2001): Efficacy of the Theory of Planned Behavior: a meta-analytic review. In *The British journal of social psychology* 40 (Pt 4), pp. 471–499. DOI: 10.1348/014466601164939.

Bantihun, Mehari Abay; Abera, Melese Worku (2019): Opportunities and challenges of adopting home garden agroforestry practices in Ethiopia: A review. In *Cogent Food & Agriculture* 5 (1). DOI: 10.1080/23311932.2019.1618522.

Bekele Jiru, Endale (2019): Review on Agro-forestry System and Its Contribution in Ethiopia. In *IJSMIT* 5 (1), p. 8. DOI: 10.11648/j.ijsmit.20190501.12.

Belay, Beyene; Zewdie, Solomon; Mekuria, Wolde; Abiyu, Abrham; Amare, Dagninet; Woldemariam, Tadesse (2019): Woody species diversity and coffee production in remnant semi-natural dry Afromontane Forest in Zegie Peninsula, Ethiopia. In *Agroforest Syst* 93 (5), pp. 1793–1806. DOI: 10.1007/s10457-018-0285-8.

Borges, J.A.R.; Lansink, A.G.J.M.O.; Emvalomatis, G. (2019): Adoption of innovation in agriculture: a critical review of economic and psychological models. In *Int. J. Innovation and Sustainable Development* 13 (1), pp. 36–56.

Borges, João Augusto Rossi; Oude Lansink, Alfons G.J.M.; Marques Ribeiro, Claudio; Lutke, Vanessa (2014): Understanding farmers' intention to adopt improved natural grassland using the theory of planned behavior. In *Livestock Science* 169, pp. 163–174. DOI: 10.1016/j.livsci.2014.09.014.

Borremans, Lieve; Reubens, Bert; van Gils, Bert; Baeyens, Dorien; Vandevelde, Céline; Wauters, Erwin (2016): A sociopsychological analysis of agroforestry adoption in Flanders: understanding the discrepancy between conceptual opportunities and actual implementation. In *Agroecology and Sustainable Food Systems* 40 (9), pp. 1008–1036. DOI: 10.1080/21683565.2016.1204643.

Buyinza, Joel; Nuberg, Ian K.; Muthuri, Catherine W.; Denton, Matthew D. (2020): Psychological Factors Influencing Farmers' Intention to Adopt Agroforestry: A Structural Equation Modeling Approach. In *Journal of Sustainable Forestry* 39 (8), pp. 854–865. DOI: 10.1080/10549811.2020.1738948.

Buyinza, Joel; Nuberg, Ian K.; Muthuri, Catherine W.; Denton, Matthew D. (2021): Farmers' Knowledge and Perceptions of Management and the Impact of Trees on-Farm in the Mt. Elgon Region of Uganda. In *Small-scale Forestry*. DOI: 10.1007/s11842-021-09488-3.

Central Statistics Authority (CSA) (2007): National statistics. Available online at http://www.csa.gov.et/.

Chan, Lucy; Bishop, Brian (2013): A moral basis for recycling: Extending the theory of planned behavior. In *Journal of Environmental Psychology* 36, pp. 96–102. DOI: 10.1016/j.jenvp.2013.07.010.

Coe, Richard; Sinclair, Fergus; Barrios, Edmundo (2014): Scaling up agroforestry requires research 'in' rather than 'for' development. In *Current Opinion in Environmental Sustainability* 6, pp. 73–77. DOI: 10.1016/j.cosust.2013.10.013.

CSA (2022): Population of Woredas as of July 2021. Central Statistics Authority (CSA). Addis Abeba. Available online at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.statsethiopia.gov.et/wp-content/uploads/2020/08/Population-of-Weredas-as-of-July-2021.pdf.

Davis, Rachel; Campbell, Rona; Hildon, Zoe; Hobbs, Lorna; Michie, Susan (2015): Theories of behavior and behavior change across the social and behavioral sciences: a scoping review. In *Health psychology review* 9 (3), pp. 323–344. DOI: 10.1080/17437199.2014.941722.

Dessie, Abebe Birara; Abtew, Asmamaw Alemu; Koye, Abebe Dagnew (2019): Determinants of the production and commercial values of Eucalyptus woodlot products in Wogera District, Northern Ethiopia. In *Environ Syst Res* 8 (1). DOI: 10.1186/s40068-019-0132-6.

FAO (2020): Agroforestry:Definition. Available online at http://www.fao.org/forestry/agroforestry/80338/en/, checked on 8/7/2020.

Fielding, Kelly S.; Terry, Deborah J.; Masser, Barbara M.; Hogg, Michael A. (2008): Integrating social identity theory and the theory of planned behavior to explain decisions to engage in sustainable agricultural practices. In *The British journal of social psychology* 47 (Pt 1), pp. 23–48. DOI: 10.1348/014466607X206792.

Fishbein, M.; Ajzen, I. (2010). Predicting and Changing Behavior:The Reasoned Action Approach. New York: Psychology Press (Taylor & Francis).

Fornell, Claes; Larcker, David F. (1981): Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. In *Journal of Marketing Research* 18 (1), pp. 39–50. Available online at http://www.jstor.org/stable/3151312.

Gagne, Camille; Goding, Gaston (2000): The Theory of Planned Behavior: Some Measurement Issues Concerning Belief-Based Variables. In *Journal of Applied Social Psychology* 30 (10), pp. 2173–2193.

Glover, Dominic; Sumberg, James; Andersson, Jens A. (2016): The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. In *Outlook Agric* 45 (1), pp. 3–6. DOI: 10.5367/oa.2016.0235.

Godin, G.; Kok, G. (1996): The theory of planned behavior: a review of its applications to health-related behaviors. In *American journal of health promotion : AJHP* 11 (2), pp. 87–98. DOI: 10.4278/0890-1171-11.2.87.

Hirschey, Rachel; Bryant, Ashley Leak; Macek, Catherine; Battaglini, Claudio; Santacroce, Sheila; Courneya, Kerry S. et al. (2020): Predicting physical activity among cancer survivors: Meta-analytic path modeling of longitudinal studies. In *Health psychology : official journal of the Division of Health Psychology, American Psychological Association* 39 (4), pp. 269–280. DOI: 10.1037/hea0000845.

Hussain, Tanveer; Khan, Ghulam Sarwar; Khan, Shahid Ali; Masood, Nasir; Ashfaq, Muhammad; Sarwer, Naila (2012): Farmers’ Agro forestry in Pakistan, Farmers’ Role-Trends and Attitudes. In *Current Research Journal of Social Sciences* 4 (1), pp. 29–35.

Kaiser, Florian G.; Hubner, Gundula; Bogner, Franz X. (2005): Contrasting the Theory of Planned Behavior With the Value-Belief-Norm Model in Explaining Conservation Behavior1. In *J Appl Social Pyschol* 35 (10), pp. 2150–2170. DOI: 10.1111/j.1559-1816.2005.tb02213.x.

Kan, Matthew P. H.; Fabrigar, Leandre R. (2017): Theory of Planned Behavior. In Virgil Zeigler-Hill, Todd K. Shackelford (Eds.): Encyclopedia of Personality and Individual Differences, vol. 50. Cham: Springer International Publishing, pp. 1–8.

Kebebew, Z.; Ayele, G. (2010): Profitablity and household income contribution of growing Eucalyptus globules(Labill) to smallholder farmers: the case of central highland of Oromia, Ethiopia. In *Eur J For.* 2 (1), pp. 25–29.

Leeuw, Astrid de; Valois, Pierre; Ajzen, Icek; Schmidt, Peter (2015): Using the theory of planned behavior to identify key beliefs underlying pro-environmental behavior in high-school students: Implications for educational interventions. In *Journal of Environmental Psychology* 42, pp. 128–138. DOI: 10.1016/j.jenvp.2015.03.005.

López-Mosquera, Natalia (2016): Gender differences, theory of planned behavior and willingness to pay. In *Journal of Environmental Psychology* 45, pp. 165–175. DOI: 10.1016/j.jenvp.2016.01.006.

Lubell, Mark; Niles, Meredith; Hoffman, Matthew (2014): Extension 3.0: Managing Agricultural Knowledge Systems in the Network Age. In *Society & Natural Resources* 27 (10), pp. 1089–1103. DOI: 10.1080/08941920.2014.933496.

Mbow, Cheikh; van Noordwijk, Meine; Prabhu, Ravi; Simons, Tony (2014): Knowledge gaps and research needs concerning agroforestry's contribution to Sustainable Development Goals in Africa. In *Current Opinion in Environmental Sustainability* 6, pp. 162–170. DOI: 10.1016/j.cosust.2013.11.030.

McDermott, Máirtín S.; Oliver, Madalyn; Svenson, Alexander; Simnadis, Thomas; Beck, Eleanor J.; Coltman, Tim et al. (2015): The theory of planned behavior and discrete food choices: a systematic review and meta-analysis. In *The international journal of behavioral nutrition and physical activity* 12, p. 162. DOI: 10.1186/s12966-015-0324-z.

Meijer, Seline S.; Catacutan, Delia; Ajayi, Oluyede C.; Sileshi, Gudeta W.; Nieuwenhuis, Maarten (2015a): The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. In *International Journal of Agricultural Sustainability* 13 (1), pp. 40–54. DOI: 10.1080/14735903.2014.912493.

Meijer, Seline S.; Catacutan, Delia; Sileshi, Gudeta W.; Nieuwenhuis, Maarten (2015b): Tree planting by smallholder farmers in Malawi: Using the theory of planned behavior to examine the relationship between attitudes and behavior. In *Journal of Environmental Psychology* 43, pp. 1–12. DOI: 10.1016/j.jenvp.2015.05.008.

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Nohmi, Makoto; Tsubo, Mitsuru et al. (2017): Factors Affecting Small-Scale Farmers' Land Allocation and Tree Density Decisions in an Acacia decurrens-Based taungya System in Fagita Lekoma District, North-Western Ethiopia. In *Small-scale Forestry* 16 (2), pp. 219–233. DOI: 10.1007/s11842-016-9352-z.

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Tsubo, Mitsuru; Ayalew, Zemen; Abele, Steffen (2020): Economic and financial sustainability of an Acacia decurrens-based Taungya system for farmers in the Upper Blue Nile Basin, Ethiopia. In *Land Use Policy* 90, p. 104331. DOI: 10.1016/j.landusepol.2019.104331.

Ofoegbu, Chidiebere; Ifejika Speranza, Chinwe (2017): Assessing rural peoples' intention to adopt sustainable forest use and management practices in South Africa. In *Journal of Sustainable Forestry* 36 (7), pp. 729–746. DOI: 10.1080/10549811.2017.1365612.

Sereke, F.; Dobricki, M.; Wilkes, J.; Kaeser, A.; Graves, A. R.; Szerencsits, E.; Herzog, F. (2016): Swiss farmers don't adopt agroforestry because they fear for their reputation. In *Agroforest Syst* 90 (3), pp. 385–394. DOI: 10.1007/s10457-015-9861-3.

Smith, Mark Stafford; Mbow, Cheikh (2014): Editorial overview: Sustainability challenges: Agroforestry from the past into the future. In *Current Opinion in Environmental Sustainability* 6, pp. 134–137. DOI: 10.1016/j.cosust.2013.11.017.

Sniehotta, Falko F.; Presseau, Justin; Araújo-Soares, Vera (2014): Time to retire the theory of planned behavior. In *Health psychology review* 8 (1), pp. 1–7. DOI: 10.1080/17437199.2013.869710.

Sok, Jaap; Borges, Joao Rossi; Schmidt, Peter; Ajzen, Icek (2021): Farmer Behavior as Reasoned Action: A Critical Review of Research with the Theory of Planned Behavior. In *J Agric Econ* 72 (2), pp. 388–412. DOI: 10.1111/1477-9552.12408.

StataCorp. (2013): Stata: Release 13. Statistical Software. Stata. College Station, TX: StataCorp LP.

Tefera, Berihun; Kassa, Habtemariam (2017): Trends and Driving Forces of Eucalyptus Plantation by Smallholders in the Lake Tana Watershed of Ethiopia. In Krystyna Stave, Goraw Goshu, Shimelis Aynalem (Eds.): Social and Ecological System Dynamics, vol. 66. Cham: Springer International Publishing (AESS Interdisciplinary Environmental Studies and Sciences Series), pp. 563–580.

Tittonell, Pablo (2014): Livelihood strategies, resilience and transformability in African agroecosystems. In *Agricultural Systems* 126, pp. 3–14. DOI: 10.1016/j.agsy.2013.10.010.

Wendorf, Craig A. (2002): Comparisons of Structural Equation Modeling and Hierarchical Linear Modeling Approaches to Couples' Data. In *Structural Equation Modeling: A Multidisciplinary Journal* 9 (1), pp. 126–140. DOI: 10.1207/S15328007SEM0901_7.

Wikipedia (2020): Amhara Region. Wikipedia: The Free Encyclopedia. Available online at https://en.wikipedia.org/wiki/Amhara_Region.

Wondie, Menale; Mekuria, Wolde (2018): Planting of Acacia decurrens and Dynamics of Land Cover Change in Fagita Lekoma District in the Northwestern Highlands of Ethiopia. In *Mountain Research and Development* 38 (3), pp. 230–239. DOI: 10.1659/MRD-JOURNAL-D-16-00082.1.

Yitaferu, Birru; Abewa, Anteneh; Amare, Tadele (2013): Expansion of Eucalyptus Woodlots in the Fertile Soils of the Highlands of Ethiopia: Could It Be a Treat on Future Cropland Use? In *JAS* 5 (8). DOI: 10.5539/jas.v5n8p97.

Zubair, Muhammad; Garforth, Chris (2006): Farm Level Tree Planting in Pakistan: The Role of Farmers' Perceptions and Attitudes. In *Agroforest Syst* 66 (3), pp. 217–229. DOI: 10.1007/s10457-005-8846-z.

## 4.4. Adoption under the influence of innovation attributes: the case of agroforestry innovations from Ethiopia

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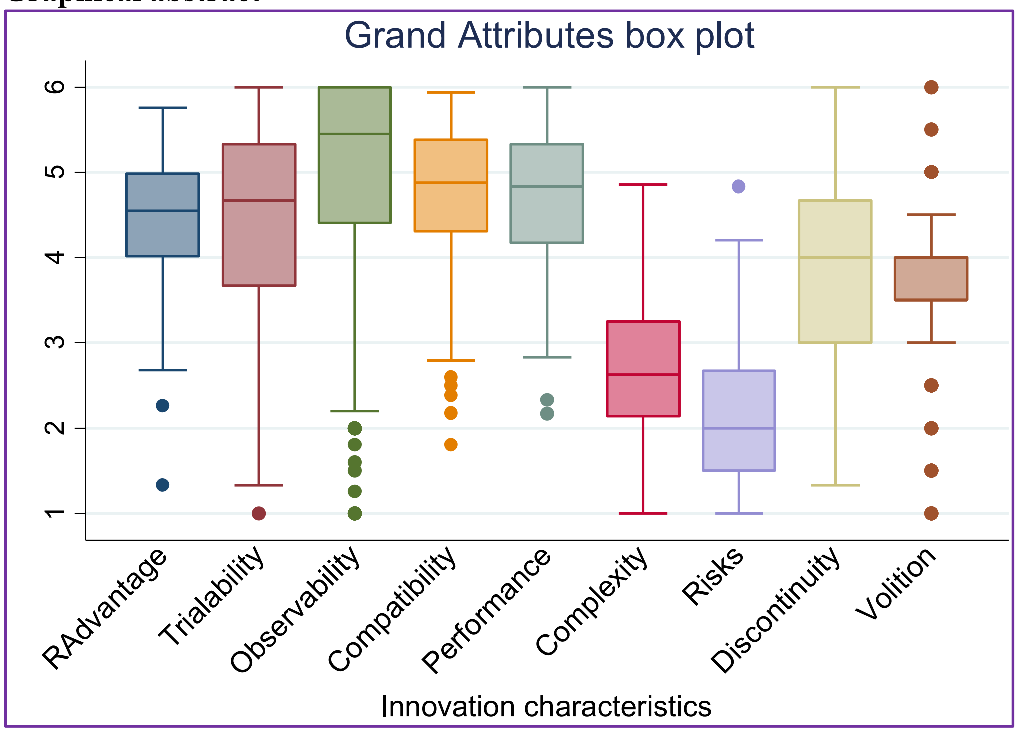
**Graphical abstract**




- The agroforestry innovations have fairly desirable attributes
- The possession of these desirable attributes positively influences the adoption
- Relative advantage is the prominent attribute desired for making adoption decisions

**ABSTRACT**

Attributes of innovation generally determine adoption decisions by farmers. We employed an extended model of innovation attributes to examine how attributes affect the adoption intensity of three agroforestry innovations. We identified factors influencing the farmers' follow-up adoption decisions over three consecutive rounds after initial innovation adoption to understand better how farmers confirm (or reject) more intensive adoption after initial positive (or negative) experiences with the innovation. In addition to their effect on revealed adoption, we tested how these factors affect adoption intention, a proxy for sustained or long-term adoption. We found that innovation attributes such as performance, risk, discontinuity, and volition are important additional attributes that form part of the decision to practice agroforestry. Biological performance (such as uniform maturity), market opportunities that generate relatively better income, and social benefits determine 7%-59% of the variation in the smallholders' actual adoption decisions. Ten principal components influenced the adoption intention but not by observability, the task it requires to produce, and the available product options of the agroforestry innovations. Overall, the study provides a detailed account of innovation attributes' contribution to making agroforestry adoption decisions under smallholder contexts.

Keywords: Diffusion of innovations theory, temporal analysis, Amhara region, woodlot, *Eucalyptus globulus*, *Acacia decurrens*, *Yushania alpine*

## 1. Introduction

Innovation attributes strongly correlate with farmers' adoption decisions of agricultural technologies, as Rogers (1983) suggested in his seminal work on the diffusion of innovations. The primary innovation characteristics proposed by Rogers comprise relative advantage (i.e., the degree to which the innovation appears better than other alternatives), compatibility (i.e., the degree to which the innovation is consistent with existing practices, needs, norms, and values), complexity (i.e., the degree to which the innovation is perceived as difficult to understand or practice), trialability (i.e., the degree of experiencing or experimenting the innovation on a limited scale before ultimate adoption), and observability (i.e., the degree to which likely adopters can see the innovation or its result (Rogers 2003, 1995). Adopting agents (e.g., consumers and farmers) evaluate the information about the innovation to make an adoption decision (Flight et al. 2011). Rogers (2003) quantified the contribution of innovation attributes to the overall adoption decision in terms of explained variance to range between 49-87%. While this claim is to be confirmed, innovation attributes were found to strongly affect the adoption decisions of farmers in numerous studies (Adesina 1993; Farquharson et al. 2013). The proposition has been popular ever since and continues to be utilized for investigating the adoption of different innovations across disciplines (Flight et al. 2011; Miller 2015).

Various context-specific characteristics of innovations were found to influence the adoption agents' adoption decisions. Adoption research in health, information technology, and management sciences frequently employed the notion of innovation characteristics for assessing the adoption of specific products and or services (Basera and Dhliwayo 2013; Vagnani and Volpe 2017; Scott et al. 2008). Individual consumers' adoption of farming techniques, television, home energy conservation methods, and medical practices of individual doctors were investigated by applying the insights of innovation characteristics (Tornatzky and Klein 1982). Beyond individual adoption decisions, researchers also employed the concept of innovation characteristics for investigating organizational level innovation adoptions, particularly in the education, petroleum refining, and transport sectors (Tornatzky and Klein 1982).

The application of innovation characteristics to innovation adoption studies remained haphazard. While in principle well suited to systematically investigate and compare a group of similar innovations, researchers often employed the concept to an arbitrary set of single, largely dissimilar innovations and often used fewer attributes than proposed initially by Rogers. For example, a review of 76 studies by Tornatzky and Klein (1982) found that 47% and 54% of the studies employed a single attribute and a single innovation for assessing the effect of innovation characteristics on adoption decisions. Likewise, a review by Kapoor et al. (2013) illustrated that while studies conducted from 1996-2011 frequently (more than 90%) employed compatibility (99.58%), relative advantage (95.58%), and complexity characteristics (92.48%), they failed to regularly incorporate observability (62.83%) and trialability (62.39%) characteristics. Hence, findings are often limited, inconsistent, and unsuitable for future research and development. Lately, Flight et al. (2011) developed and tested a comprehensive list of innovation attributes applicable to many innovations. In agriculture, the notion is employed for identifying desirable attributes for selecting crop varieties (Miriti et al. 2022), mechanization implements (Gandasari 2021), climate smart innovations (Senyolo et al. 2018), precision agriculture (Le Hoang Nguyen et al. 2022) and constraint based innovations (Oca Munguia and Llewellyn 2020).

In agroforestry (AF), i.e., the production of perennial trees in combination with crops and/or livestock in spatial and temporal arrangements (FAO 2022), the innovation characteristics concept has rarely been applied to study innovation adoption. Information on the number of attributes typically employed in such studies is not readily available. Notwithstanding, innovation attributes are essential for adopting agroforestry innovations (AFI) as farmers seek information on innovation once they have become aware of it and form an attitude towards the innovation relative to current practices and non-AFI alternatives (Reed 2007). Recognizing the importance of innovation characteristics, Reed (2007) proposed participatory AFI development to enhance widespread uptake and diffusion by facilitating attributes-based selection of innovations. In summary, innovation characteristics have a central role in the adoption decisions of smallholder farmers.

Despite more than 50 years of research on the role of innovation attributes in the adoption decision, the need for further research in this area has been highlighted (Flight et al. 2011). Further research needs comprise the evaluation of the concept on a wide array of innovations (Flight et al. 2011) or across multiple innovations (Tornatzky and Klein 1982), assessing the impact of innovation characteristics beyond initial adoption or on perpetual implementation (Tornatzky and Klein 1982; Kapoor et al. 2014), measuring innovations based on actual perceptions of potential adopters (Tornatzky and Klein 1982), quantitative empirical results as opposed to the predominant descriptive studies (Tornatzky and Klein 1982; Kapoor et al. 2014), repeated measures (i.e., panel or retrospective) based empirical assessments (Tornatzky and Klein 1982), and development of detail layer of specifications for more accurate prediction of changes in adoption patterns (Flight et al. 2011). Beyond these general suggestions, the contribution of innovation characteristics to the ultimate adoption of various AFI has rarely been investigated by previous research apart from erratic descriptive studies. This research gap undermines the comprehensive understanding of factors influencing the adoption of AFI in smallholder contexts (Amare and Darr 2020). Consequently, the current study was initiated to close this gap in AFI adoption decision studies. We explore the contribution of innovation attributes on smallholder farmers' adoption decisions of three selected AFI in the Amhara region of Ethiopia.

The objectives of this study are (i) to empirically test the concept of innovation attributes on adoption decisions of multiple AFI; (ii) to test the durational effect of innovation attributes on the AFI adoption decision by employing repeated measures from retrospective data; and (iii) to evaluate the sufficiency of the initial five attributes proposed by Rogers. By demonstrating the importance of innovation attributes as major adoption decision criteria, we aim to embolden awareness among researchers and development practitioners, eventually leading to better development results and research outputs.

Our research explores new environment, particularly concerning the second research objective. While based on Rogers (2003) classical definition of innovations as ideas, objects, or practices perceived as new by an individual, adoption research has typically investigated the process of adopting (or not) innovations for the first time, we extend the concept and trace the adoption of the three specific AFI over a longer period thereby covering repeated rounds of adoption decisions over several cycles (termed first/initial, second-round adoption etc. in our paper). This implies that after the initial adoption, farmers were able to familiarize themselves with these AFI in the meantime, test or modify the innovation, and expand, continue, reduce, or abandon adoption. Our research allows us to draw lessons associated with the factors driving the progression of the AFI adoption process over several consecutive rounds, in line with Tornatzky and Klein (1982), who suggested considering implementation beyond one-time adoption. In addition to current adoption that prevails in most AF adoption studies, we also examine the intention for sustained adoption, which we use as a proxy for post implementation. Exploring sustained adoption provides additional information on factors that influence continued adoption of these AFI in the long term. We do this by employing structural equation modeling of a latent variable from newly produced principal components.

Our paper is the first of its kind to investigate the influence of AFI attributes on adoption in a smallholder context and to employ temporal analysis to trace changes throughout three consecutive adoption rounds. In addition, we aim to contribute to the literature by presenting a comprehensive measurement scale of perceived innovation attributes in AFI, which does not currently exist to the best of our knowledge. Our analysis of the factors influencing adoption improves our understanding of the adoption context by revealing the variability of such factors over time. This, in turn, can contribute to the design of more effective policy and development interventions aimed at promoting AF adoption during specific adoption phases.

## 2. Theoretical framework

The diffusion of innovations theory (Rogers 1983, 1995, 2003) is an established theory applied across all ranges of technology adoption. Introduced in 1962 and continuously developed through to 2003, the theory classifies farmers into various innovator categories. It emphasizes the reinvention of products and behaviors to make them better fit the needs of adopter agencies (Wani and Ali 2015). According to Rogers (1983), the adoption rate of an innovation is determined by perceived attributes of the innovation, types of the innovation decision, communication channels, nature of the social system, and promotion efforts of change agents (Miller 2015). Relative advantage, compatibility, complexity, trialability, and observability of the innovation were identified as most relevant for the farmers' adoption decisions. The diffusion of innovations theory has been widely criticized, among others, for ignoring differences in farmers' circumstances and the lack of fit of the technology to their respective needs (Hoffmann 2007). Decision theories (profit and utility maximization and risk minimization) are, furthermore, deemed to provide a more rigorous explanation of how smallholder farmers arrive at optimal decisions (Umar 2014). Network models serve as an alternative analysis framework in diffusion research (Windsor et al. 2022; Carrington et al. 2012). Notwithstanding these criticisms and alternative theoretical angles, Lai (2017) suggested that the diffusion of innovations theory is suitable for examining the actual usage of the innovation, which is in congruence with our primary intention.

Building on Rogers theory, the importance of innovation attributes has been embraced (Oca Munguia and Llewellyn 2020) and frequently explored in information technology and health related subjects (Kapoor et al. 2014). Researchers have modified the initial five attributes proposed by Rogers. Flight et al. (2011) developed 15 constructs with 43 items and evaluated the effect of innovation attributes on the adoption of high-tech consumer products (i.e., camera, player, and DVD player). To increase the depth of the construct Eiamkanchanalai and Assarut (2012) modified the concept of innovation attributes to include perceived risk, customization, volition, and social benefits.

In AF, we cannot locate any study conducted by employing innovation attributes, to the best of our knowledge. We, therefore, developed new attributes specific to AFI and largely adapted and appropriately modified (i.e., by using generalization, abstraction, and analogy) existing indicators from other studies to fit our context (Table 2). The adaptation and development allowed us to include a broader set of attributes beyond the originally proposed ones, which was hardly pursued in other AF studies.

## 3. Methods

**Study areas:** The study was conducted in the Amhara region (11°39'39"N 37°57'28" E) of Ethiopia. The adoption of AF technologies remains a topic of high relevance in this country as reflected by the country's policy of green economy, large smallholder population (around 85% of 110 million), climate change proneness, and the existence of a variety of socio-demographic and ecological conditions that facilitate a diversity of AF practices. The potential of adopting AF for income, climate change adaptation, and ensuring ecosystem services remains high. The Amhara regional state was selected due to the existence of various farming systems, AF practices, and the variety of motivations and outcomes around these (Amare and Darr, 2022).

Three districts were purposively selected based on the prevalence of specific AFI practices, particularly farm woodlots, which represent the focus of the current research. Woodlots were selected as they, in contrast to many other AFI systems, the adoption of which is often characterized by risk avoidance and smaller scales, are typically practiced by farmers on relatively large plots of land relative to total farm size and hence are suitable to reveal how farmers make high-impact AFI adoption decisions (Amare et al. 2019). Three types of farm woodlots were studied, i.e., *Acacia decurrens* (hereafter acacia), *Eucalyptus camadulensis* (hereafter eucalyptus), and *Yushania alpine* (hereafter bamboo). Woodlots are an important AFI system in Ethiopia that involve a variety of crop-livestock combinations, such as farmers cultivating crops and trees on the same plot of land during the initial years and/or using the woodlots for grazing and/or fodder production. The three AFI are widely adopted by farmers in the region due to their relative economic benefits compared to farming. The districts cover a range of environmental and farming conditions, from high crop production potential areas suitable for a diversity of crops (Mecha district), to areas with limited crop production options (Fagita Lekoma district) and highly degraded sites (Banja district).

**Sampling and data collection:** A multi-stage sampling procedure was followed to select farmers. After the districts were purposively selected, 27 representative Kebeles (lowest level administration in Ethiopia) were selected in each district based on the prevalence of the specific AFI and their importance in the farming systems with input from district experts and heads of the bureaus of agriculture. In consultation with Kebele experts, a sampling frame was made of only the farmers who had been practicing, expanding, reducing, or abandoning the innovation, excluding non-practitioners. The total sample size was 385 by employing Cochran's (1963) sample size determination formula. Nonetheless, due to information saturation, we quit conducting household interviews after 327 households. Proportion to population size (PPS) was used to determine the sample size from each district. Seven female farmers were interviewed in the absence of their husbands, who are the predominant respondents in married couples. While temporal analysis of adoption decision-making over consecutive rounds would, in principle, have benefitted from the availability of panel data, the application of retrospective data in lieu of scarce panel data is widely accepted given its superiority in terms of information abundance compared to cross-sectional data (Gibson and Kim 2005; Assaad et al. 2018). This was also the approach followed in the current study.

**Setting constructs (attributes) and items:** In order to obtain a complete list of AFI attributes, the below procedures were followed for developing the items and constructs: (1) conducting an extensive literature review on innovation characteristics across innovations of different types (e.g., manufactured goods) (e.g., Flight 2011; Westrick et al. 2009; Evans 1988; Reed 2007; Bozbay et al. 2008; Basera and Dhliwayo 2013; Eiamkanchanalai and Assarut, 2019); (2) selection of Flight et al. (2011) as the most comprehensive guiding work for construct and item lists development; (3) setting constructs and criteria following Flight et al. (2011) which resulted in 39 items; (4) incorporating AFI-specific characteristics (Shiksha 2022); (5) inclusion of constructs and attributes found during the exploratory survey; and (6) developing the constructs and attributes by combining steps 3, 4 and 5. Ultimately, we developed 9 constructs, with 65 items (Supp. Table 1), for assessing the attributes of AFI driving the smallholder farmers' adoption decisions (Table 2). In order to obtain a more detailed understanding, the attributes of relative advantage, compatibility, and observability are sub-categorized into three, two, and two sub-groups. Experimentation is combined with trialability, while performance consistent with adaptability is separately retained and examined. In addition to the 5 original attributes (Rogers 1983, 1995, 2003), we added 4 more constructs that widely relate to AFI, namely; (1) volition, i.e., voluntary AFI adoption; (2) disinvestment, i.e., ease of withdrawing from the AFI; (3) performance, i.e., fit of the AFI to biophysical conditions leading to vigorous growth; and (4) risk, i.e., production and marketing uncertainties.

Table 1. AFI attributes developed for this study

| Construct | Sub-constructs | No. of items | Literature* |
|---|---|---|---|
| **Relative advantage** | Biophysical | 9 | Rogers (2003); Bozbay and Yasin (2008); Westrick and Mount (2009); Kapoor et al (2013); Eiamkanchanalai and Assarut (2012); Baser and Dhilwayo (2013) |
| | Economic | 7 | |
| | Social | 3 | |
| **Compatibility** | Personal | 8 | Rogers (2003); Bozbay and Yasin (2008) |
| | Social | 3 | |
| **Complexity** | | 8 | Rogers (2003); Eiamkanchanalai and Assarut (2012) |
| **Observability** | Observe | 4 | Rogers (2003); Bozbay and Yasin (2008) |
| | Communicate | 1 | |
| **Trialability** | | 3 | Rogers (2003); Flight et al. (2011) |
| **Discontinuity** | | 3 | Flight et al. (2011) |
| **Performance** | | 7 | Flight et al. (2011) |
| **Risk** | | 6 | Eiamkanchanalai and Assarut (2012) |
| **Volition** | | 2 | Eiamkanchanalai and Assarut (2012); Flight et al. (2011) |

*we also consulted general literature, including Shiksha (2022), for identifying and incorporating AFI attributes

**Data analysis**: data was analyzed by employing descriptive statistics, principal component analysis, multiple linear regression, and structural equation modeling. Descriptive statistics were used to describe the characteristics of the innovations based on attributes. Further, principal component analysis was employed to reduce the number of variables and reveal independent factors that largely explain the variation of the target variable (Amare and Darr, 2022; Jolliffe and Cadima, 2016). Consequently, multivariate regression was employed to assess the impact of the newly produced factors on farmers' adoption. We assessed adoption decisions in three consecutive rounds to assess the relationship between AFI adoption decisions and factors influencing these decisions over time. By doing so, we improve previous predominantly event-based cross-sectional analyses. Ultimately, the structural equation modeling technique was used to analyze the newly formed variables' effect on smallholders' sustained adoption intention(Wendorf 2002; Amare and Darr 2022). Stata 12 software was used for the analyses.

**Statistical tests:** Reliability tests were conducted. Cronbach's α reliability test was employed to establish internal consistency of the items, ensuring that they refer to similar unobserved/latent variables (Supp. Table 2). Also, the Kaiser-Meyer-Olkin (KMO) test and discriminant analysis proved the suitability of the dataset for PCA. The data showed the absence of multicollinearity between the variables. Trialability, discontinuity, risk, and volition were excluded from further regression analysis due to low reliability (Supp. Table 2).

## 4. Results

### 4.1. Descriptive summary of the AFI

Adoption of the three AFI spans the period from 1959 to 2019. Overall, 327 farmers in our sample adopted the AFI at any time during this period, while less than half (130) expanded their adoption later in a second round. Further expansion of adoption is limited to a few farmers as only 52, 11, and 3 smallholders made consecutive AFI adoption decisions in the third, fourth, and fifth cycles. This indicates that while some farmers expanded or re-established the AFI in the second and third adoption rounds, most farmers abandoned the AFI in further decision-making cycles. This does not mean that they immediately abandoned or even uprooted their AFI, given the huge financial loss that this would imply. However, while continuing this AFI until the end of its rotation, farmers refrained from further adoption and expansion of the AFI area in later cycles. Given low numbers in round 4 and beyond, we limit our analyses to three cycles of adoption decision-making in further analyses.

Figure 1 displays the perception of the respective AFI by smallholder farmers. In descending order, the mean Likert values of observability, compatibility, performance, trialability, and relative advantage are above four (of the maximum 6). Regarding discontinuity and volition, the mean Likert values lie between 4 and 3. The attributes risks and complexity have the lowest mean Likert values. Thus, the farmers' assessments indicate that these AFI generally possess desirable characteristics that farmers prefer. We discuss the attributes in more detail below, with numbers in brackets representing the mean Likert value.

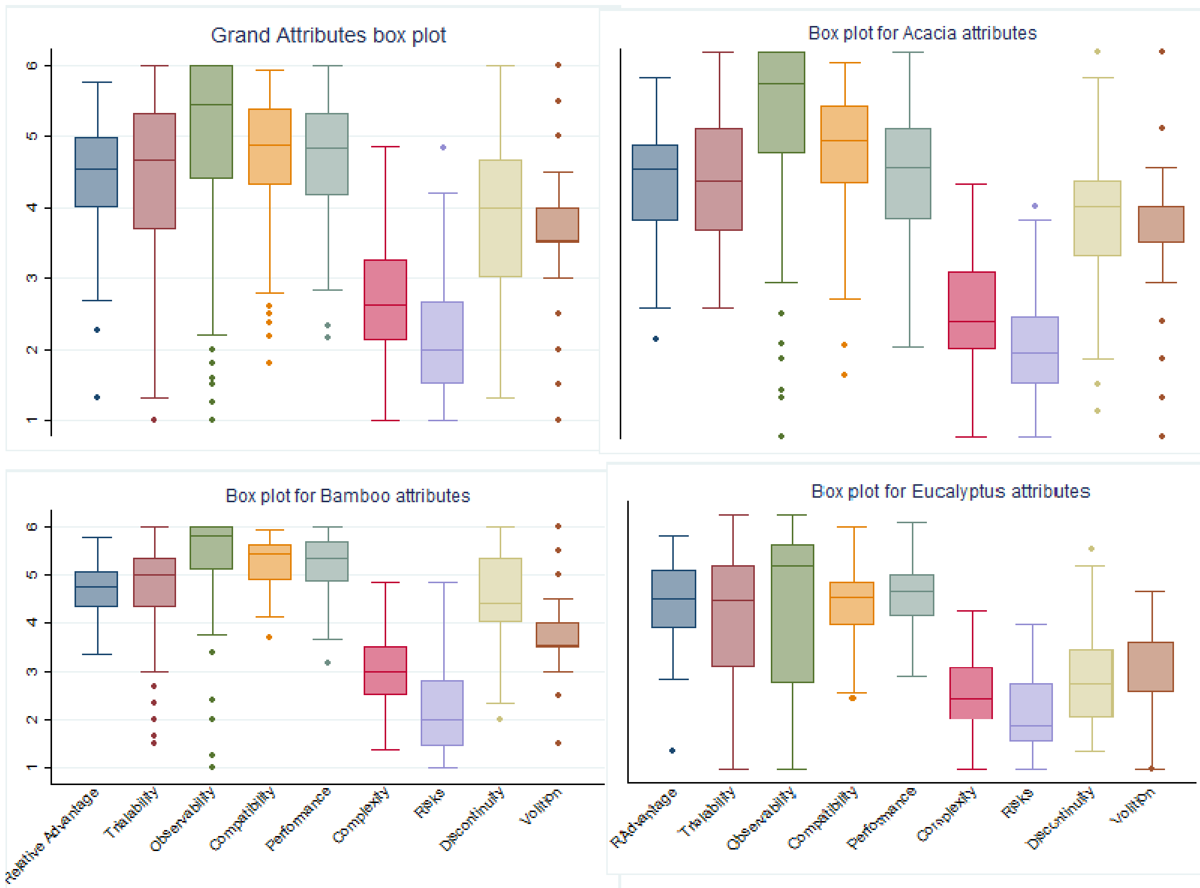



Figure 2. Perception of the AFI attributes by smallholder farmers (y-axis represents mean Likert values with 1=very low to 6=very high, and x-axis shows innovation characteristics)

**Relative advantage**

As stated in Table 2, the relative advantage comprises sub-constructs related to the AFI's biophysical, economic, and social status-related relative advantage. Farmers rated the AFI favorably (4.45) for their attributes. Acacia (4.56) followed by bamboo (4.53) are rated significantly (F=18.02, p=0.0000) higher, while eucalyptus (4.27) scores relatively low. Among the items, 'preferable over other options' (5.10), 'reliability of economic benefits' (4.98), and 'provision of product options' (4.64) scored the highest; 'favors subsequent farm production' (3.92) and 'does not require particular land quality' (4.06) scored the lowest average values. The perceived economic advantage of the AFI was also high (4.60). In descending order, acacia (4.87), eucalyptus (4.64), and bamboo (4.23) were perceived favorably for their economic advantage. Social advantage scores were also essential and had above average values (4.18), with acacia (4.70) having a significantly (F=14.56, p=0.0000) higher value compared to bamboo (3.94) and eucalyptus (3.86). Acacia overall scored the highest average value for its relative advantage attributes.

**Compatibility**

Compatibility attributes of AFI adoption comprise personal and social compatibility. While in aggregate, the AFI exhibit an above average compatibility value (4.69), the individual innovations differ significantly, with acacia (5.24) being the most compatible (F=67.83, p=0.0000), and eucalyptus the least compatible (4.21) with the farmers' production systems. Both personal and social compatibility are relatively high for acacia (5.23, 5.26) followed by bamboo (4.46, 4.73). Relatively high acacia compatibility (5.24) is associated with its 'short rotation' period and 'soil fertility benefits from nitrogen fixation'. 'Available skill' (5.16), 'resources' (5.07) and 'climatic conditions of specific sites' (4.84) are the most important factors that favor personal compatibility of the AFI and its widespread adoption. In contrast, 'slight competition for production of staple crops' (3.55) and a 'lack of complementarity' (3.65) of the AFI reduce their personal compatibility. AFI are generally compatible with social contexts; 'social acceptance' (5.48) and 'compatibility with norms and values' (5.36) score the highest in this attribute. 'Approval by siblings and neighbors' (4.49), 'consistency with household living conditions or styles' (4.85), and 'motivation by companions or friends' (4.37) to adopt these AFI further promote the AFI social compatibility.

**Complexity**

The degree to which an AFI is perceived as difficult is critical in farmers' AFI adoption decisions. It represents the ease with which a farmer believes s/he can appropriately accomplish the tasks for effective production of the specific AFI. Smallholders rated the production of these AFI as hardly complex (2.70), with bamboo (2.55) and eucalyptus (2.58) being perceived as less complex in production compared to acacia (2.94) at a statistically significant level (F=8.44, p=0.0003). The comparatively higher complexity value for acacia is linked to specific market requirements about the desirable tree diameter, which requires proper spacing of the AFI trees during establishment. Given the primary purpose of acacia for charcoal production and the fact that consumers demand sizable charcoal chunks in their charcoal, the market prefers moderately thick acacia trees. The farmers need to adjust the spacing among acacia trees by managing plant density to avoid tree trunks that are too thin or too thick. Among the items, 'tasks related to management' (3.55) and 'marketing of the products' (2.97) are relatively complex and require a sizable effort. In contrast, 'simplicity of production techniques' (2.65), 'use of available tools for production' (2.51), and 'the available general knowledge' (2.51) make production simpler and familiar to farmers. The fact that special 'skills' (2.30) and 'overall management strategies' (2.41) are not required favors the AFI's adoption.

**Observability**

The ability to observe and communicate to other farmers and experts the performance of the AFI are deliberated in the observability attribute. On average, the AFI have very good (4.90) observability attributes. Yet, significant differences exist among the three AFI (F=4.24, p=0.0153), with observability ratings for acacia (5.18) being higher than the ratings for bamboo (4.89) and eucalyptus (4.63). The ease to 'communicate the production to other farmers and experts' (5.67) and 'common observation of its performance being produced by different farmers' (4.92) constitute the highest-ranking observability characteristics. The relatively lowest average observability rating was obtained for 'poor identification of the problems associated with the growth and performance' of the three AFIs (4.74).

**Trialability**

Trialability considers the opportunity to try, customize or experiment with the AFI to ensure that it possesses the desired features. 'Verifiable on small plot' (4.70), 'customizable on management and size of plantation' (4.50), and 'customized for unique features like charcoal and log quality' (4.33) form the attribute. Acacia (4.70) has a significantly (F=4.83, p=0.0086) higher level of trialability, whereas eucalyptus (4.36) and bamboo (4.26) reveal relatively lower levels. Overall, the AFI have fairly good trialability characteristics (4.45), indicating that farmers can easily test and adjust the AFIs before making follow-up adoption decisions.

**Discontinuity**

Discontinuity refers to the option of completely removing an established AFI plantation in the face of poor market conditions or the availability of better alternatives, which is vital for farmers to continuously adapt their operations to changing climatic and market conditions and fulfill household consumption needs. The opportunity to discontinue (i.e., disinvest from) the innovation is above average (3.80) for all three AFI. Acacia (4.54) provides a significantly (F=76.29, p=0.0000) higher opportunity for smallholders to disinvest and thereafter use the plot to produce other crops. The discontinuity score for bamboo (3.76) is lower but above average. Eucalyptus retains the lowest (2.81) disinvestment value among the three AFI, which is ascribed to its deep root system, ability to resprout from stumps, and the high physical labor input required for uprooting the trees. As reported by farmers, these properties may preclude other uses on land planted with eucalyptus trees for a long time.

**Performance**

The performance of the AFI is the primary factor driving decisions to adopt. Performance in our context is related to the vigor of the specific AFI under the prevailing bio-physical conditions against the farmers' expectations. The AFI are perceived as well (4.67) adapted to local conditions. Acacia (5.20) has a significantly (F=51.15, p=0.0000) higher performance value compared to eucalyptus (4.41) and bamboo (4.33). Farmers are satisfied (4.61) with the performance of the AFI as they are characterized by a 'high input-output efficiency' (5.00), have 'large vigorosity in growth and performance' (4.63), 'consistently produce and grow' (4.75) and overall 'perform as expected by farmers' (4.88).

**Risks**

Weather variability, pests or diseases, unpredictable market demand, and poor pricing pose huge threats to AF producers. Environmental and market uncertainties can create doubts and affect farmers' AFI adoption decisions. The smallholders rated the AFI as having slight (2.06) production-related risks. Acacia (2.19) and bamboo (2.10) have significantly higher (F=2.81, p=0.0620) risks, whereas eucalyptus (1.91) presents relatively low amounts of risk. A relatively higher risk for acacia and bamboo is associated with 'diseases susceptibility' (2.50) followed by 'poor resistance to drought' (2.38). Acacia related risk is associated with the expansion of acacia into more fertile lands, the threat from diseases, and market uncertainty, as revealed by group discussions. Overall, the AFI poses 'less health related risks' (2.00) and makes 'minor contributions to destructing land stabilization' (2.06).

**Volition**

The ability to discretionary decide to adopt (or abandon) an AFI is vital in the farmers' AFI adoption decision. While forced adoption can increase the adoption rate in the short term, the long-term commitment of farmers to such innovations remains questionable (Kansanga et al., 2021). Likewise, farmers may shy away from adopting innovations that they may not be able to disadopt at a later stage. Collectively the innovations are rated above average (3.52) for the attributes of volition, indicating that smallholders mainly adopt AFI based on voluntary decisions. A significant difference, however, existed among the innovations (F=24.40, p=0.0000), as the adoption of eucalyptus (3.06) is often perceived to be enforced unconsciously or indirectly compared to acacia (3.79) and bamboo (3.76). As revealed in group discussions, the persistent pressures exerted by neighbors and siblings in light of the innovations' anticipated profitability often lead to 'partially forced' adoption. Yet farmers also revealed contradictory perceptions by articulating voluntary based adoption pressure from significant others. Neighbors and friends 'encourage' adoption, particularly for bamboo (4.72) and acacia (4.05), while less for eucalyptus (3.54), given the negative impact of eucalyptus on neighboring plots.

Further instances of involuntary adoption confirmed from group discussions refer to farmers who felt forced to adopt AFI after a farm woodlot had been established on a neighboring land plot due to shade and associated effects on crop production. Reports of 'land death or drying-up' of crops on plots adjacent to eucalyptus woodlots are known widely in the localities. Likewise, unwanted root expansion of bamboo AFI to adjacent plots is a constant source of conflict. Consequently, farmers often feel forced to follow suit with their neighbors and establish AFI on their plots to avoid these negative consequences on their farms. 'Partial enforcement' in the form of encouragement by traders and repeated narration of benefits by experienced siblings has also been reported. Interestingly, the poor financial viability (e.g., high input cost) of current crop production has also been mentioned by respondents to motivate involuntarily AFI adoption, similar to young farmers' desire to reduce labor intensity on farm in light of available more profitable alternative off-farm employment. These cases illustrate that, while farmers essentially adopt AFI discretionally, certain conditions can drive AFI adoption involuntarily.

## 4.2. Principal component analysis

### 4.2.1. Correlation matrix

Due to the cut-off reliability test result of 0.7, only 5 of the 9 constructs are considered for principal component analysis (PCA): relative advantage, compatibility, complexity, observability, and performance. Correlation tests showed association among the 50 items invalidating the direct use of these covariates for regression analysis. Some of them, 'reliably provides cash benefits' vs. 'preferable among available farm options' (0.76), 'attractive pricing' vs. 'preferable among available farm options' (0.48), 'compatible to the local climate' vs. 'uniformly matures' (0.59), 'provides optional products' vs. 'long term production once planted' (0.48), 'compliments current production' vs. 'favors subsequent farm production' (0.63), 'fits existing livelihood strategy' vs. 'preferable among available farm options' (0.51), 'long term production once planted' vs. 'ecological benefits' (-0.59), 'establishment is observable' vs. 'performance is observable' (0.94), 'problems are observable' vs. 'establishment is observable'(0.88), 'establishment is observable' vs. 'observable as commonly produced' (0.9), 'approval by significant others' vs. 'establishment is observable' (0.64), 'neighbors encourage' vs. 'establishment is observable' (0.67), 'resource efficient' vs. 'performs as expected' (0.48), 'familiar management' vs. 'available skills' (0.65), 'technical complexity' vs. 'available skills' (0.63), 'compatible with norms' vs. 'compatible with skill and knowledge' (0.42) showed strong correlation between each other. Data is hence suitable for variable reduction techniques through PCA. Using the PCA technique, new independent variables or principal components (PCs) are created, which are linear combinations of the original innovation attribute items.

### 4.2.2. Principal components

After running a PCA on the original 50 items of the five AFI attributes, 12 PCs were retained with Eigenvalues of >=1. In combination, the retained PCs explained 72% of the variation approaching the 80% variance explanation power threshold.

Loadings (i.e., correlation between the original observed variables and scaled components) analysis is employed to identify to (from) which of the original items these 12 PCs are extracted or mainly belong. Following the rule of thumb definition of ≥0.3 loading value as the main combination of items that define the specific PC, the PCs are organized into the original items and again renamed to reflect the new combination of items (Table 3). Figure 2 displays the attributes derived from the main items that formed the respective PCs.

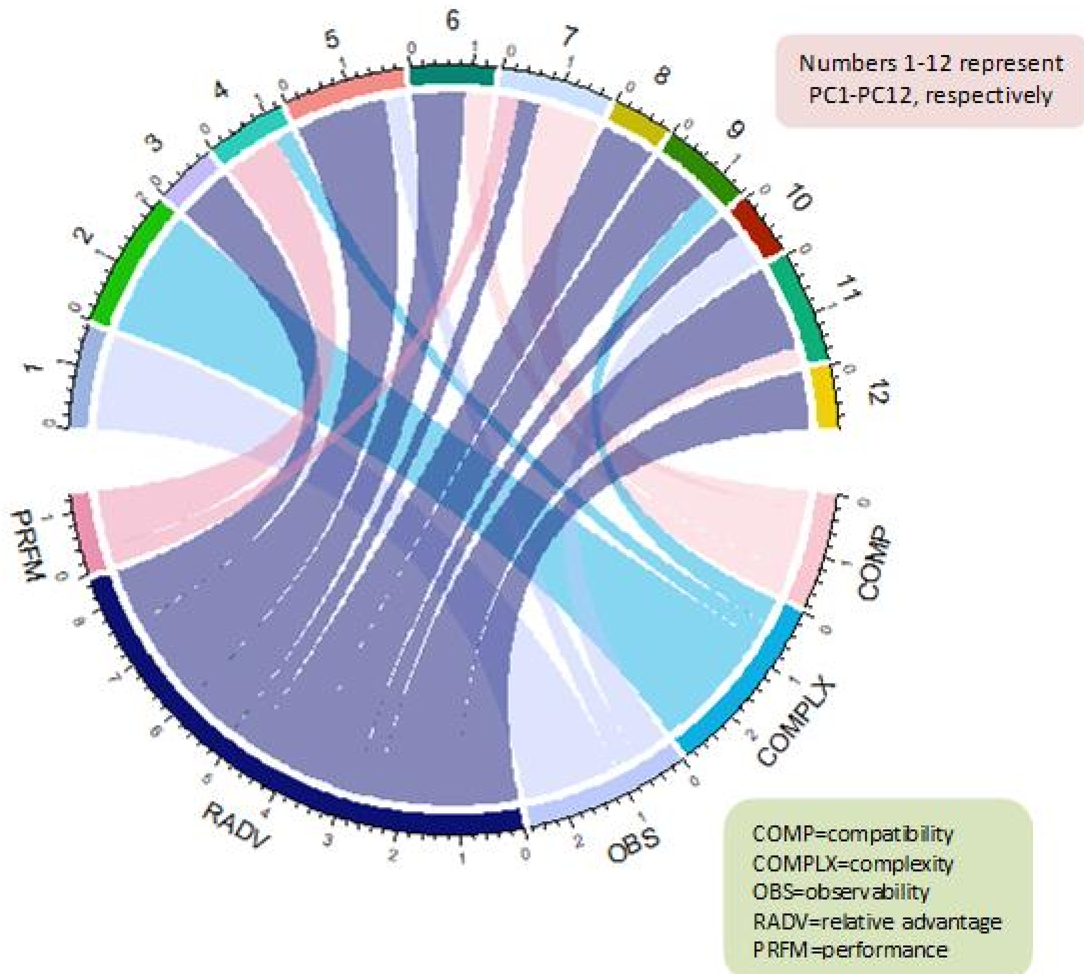



Figure 3. Diagram showing major items that loaded into the PCs (the loadings from items under similar categories are summed without considering the direction of the relationship)

Relative advantage, complexity, and observability items form the majority of PCs representing farmers' attributes based innovation adoption criteria (Fig. 2). Compatibility and performance also contribute to the decision criteria for attributes-based innovation adoption.

### 4.3. Attributes-based determinants of AFI adoption

#### 4.3.1. Determinants of actual adoption

Table 2 shows the importance of different attributes for AFI adoption during different rounds of adoption decision-making. Depending on the round of AFI adoption decisions, the PCs for 'production and marketing performance' (PC4) and 'compatibility & substantial income' (PC7) negatively influence AFI adoption. Conversely, the PCs for 'biological features and communicability' (PC5) and 'social benefits' (PC8) positively influence AFI adoption. Although we had initially incorporated additional attributes, all of these newly added attributes were excluded from regression analysis due to poor goodness–fit of the PCA rule. Consequently, items exclusively affiliated with Rogers' (2003) original five attributes are found relevant for making AFI adoption decisions. 'Production and marketing performance', 'biological features and communicability', 'compatibility and substantial income', and 'social benefits' are more important for the first-time adoption decision. During second-round adoption, the model is insignificant, implying that innovation attributes are not important for making the adoption decision. Third-round adoption of the AFI is significantly affected by the same factors that affect the first-time adoption except for 'biological features and communicability' (PC5).

Table 2. Determinants of consecutive adoption decisions

| **Principal component** | **Round of adoption** | | | **Main categories of attributes** |
|---|---|---|---|---|
| | First | Second | Third | |
| **PC1 (observability)** | 0.012 (0.046) | -0.013(0.043) | -0.026 (0.11) | Observability |
| **PC2 (complexity in production and harvesting)** | 0.035(0.049) | 0.038(0.047) | -0.11 (0.10) | Complexity |
| **PC3 (relative economic preference)** | 0.053(0.059) | 0.046(0.068) | -0.13 (0.21) | Relative advantage |
| **PC4 (production and marketing performance)** | -0.18(0.071)** | -0.131(0.074)* | -0.41 (0.17)** | Complexity and performance |
| **PC5 (biological feature and communicability)** | 0.214(0.065)*** | 0.14 (0.096) | -0.17 (0.25) | Performance and observability |
| **PC6 (complementarity & competition)** | -0.104(0.063) | -0.05 (0.072) | 0.23(0.21) | Relative advantage, compatibility |
| **PC7 (compatibility & substantial income)** | -0.13(0.061)** | -0.19(0.09)** | -0.52(0.239)* | Compatibility, relative advantage, performance |
| **PC8 (social benefits)** | 0.16(0.063)** | 0.134(0.089) | 0.61(0.20)** | Relative advantage |
| **PC9 (tasks & products)** | 0.063 (0.06) | 0.035(0.072) | 0.17(0.18) | Complexity, relative advantage |
| **PC10 (market preference & communicability)** | 0.037(0.07) | -0.005(0.1) | 0.31(0.22) | Observability, relative advantage |
| **PC11(social benefits, maturation period &compatibility)** | 0.03(0.07) | 0.025(0.08) | 0.2 (0.13) | Relative advantage, compatibility |
| **PC12 (environmental & labor demands)** | 0.03(0.07) | -0.022(0.074) | 0.06(0.21) | Performance |
| **Constant** | 1.14(0.085)*** | -0.13 (0.074)*** | -0.41 (0.17)*** | |
| **Observations** | 142 | 58 | 23 | |
| **$R^2$** | 0.2282 | 0.2637 | 0.8141 | |
| **Adjusted $R^2$** | 0.1564 | 0.0673 | 0.5910 | |
| **Residual d.f.** | 129 | 45 | 10 | |
| **F statistic** | 3.18 | 1.34 | 3.65 | |
| **Prob> F** | 0.0005 | 0.2292 | 0.0244 | |

Models=multiple linear regressions, dependent variables= size of land adopted in 'timad' (0.25ha). ***, **, * significant at 1%, 5%, and 10% level of significance. The number in brackets are standard errors (±).

'Production and marketing performance' as well as 'compatibility and substantial income'-related factors are negatively associated to first-round adoption. From discussions, it emerged that farmers carefully assess the transaction costs and trade-offs related to adopting the new innovation and of already practiced innovations. These contemplations often lead to decisions that risk AFI adoption intensity. Despite understanding the income benefits and compatibility of AFI, farmers often reduce or abandon AFI for reasons related to fulfilling food consumption needs, land scarcity, and the desire to produce diverse crops, as revealed during group discussions. Besides, most farmers adopt small areas of the AFI at the beginning of their family formation, given food consumption needs and land scarcity. These initial AFI adoption decisions mainly aim to fulfill their household's immediate consumption needs, such as the provision of construction wood, fuelwood, charcoal, and furniture. The pursuit of financial gains is hence of lower importance at this stage.

On the other hand, 'biological features and communicability' and 'social benefits' are positively correlated to first-round adoption. As expected, biological features, including uniform maturity and good climatic and edaphic adaptability, contribute to adoption decisions. Social benefits such as prestige also motivated farmers to adopt the AFI. While cash income generated from AFI investments can contribute to social prestige, innovation promotion based on financial returns alone does not often lead to AFI adoption, as indicated by the negative correlation with 'compatibility & substantial income'.

The non-significance of the model in the second decision-making cycle confirms that even if innovation attributes are important, they do not always influence adoption decisions. Instead, factors related to farm-household socioeconomic features and markets might be more relevant at this stage. In the third round, AFI adoption is affected negatively by 'production and marketing performance', and 'compatibility & substantial income' while positively influenced by 'social benefits'. While the latter result is intuitive, given that farmers continue to enjoy the benefits from social prestige they have acquired from previous adoption, the negative correlation of 'compatibility & substantial income' was not expected. Presumably, compatibility may not be necessary since farmers have already evaluated and confirmed the AFI's compatibility in prior rounds. Likewise, cash income generation opportunities do not encourage adoption decision-making at this stage, possibly because farmers' adoption decisions do not merely aim at maximizing financial benefits given trade-offs with subsistence-oriented food production. Land scarcity, risk avoidance, preference for familiar crops, environmental concerns, shortage of capital, and lack of skills are also revealed as possible causes during group discussions.

#### 4.3.2. **Determinants of sustained adoption**

In addition to revealing AFI adoption behaviors, we investigated adoption intention as a proxy for sustained or long-term adoption. Of all, the PCs 'production and marketing performance' and 'compatibility & substantial income' showed a consistent direction of relationship with adoption;

however, with different significance levels for the various rounds of decision-making. Due to the differences among the years for the other 10 PCs, we investigated how these factors affect adoption intentions using structural equation modeling (Figure 3). Except for 'observability' and 'tasks & products', all PCs are significantly correlated to the latent variable and predict sustained adoption of AFI.

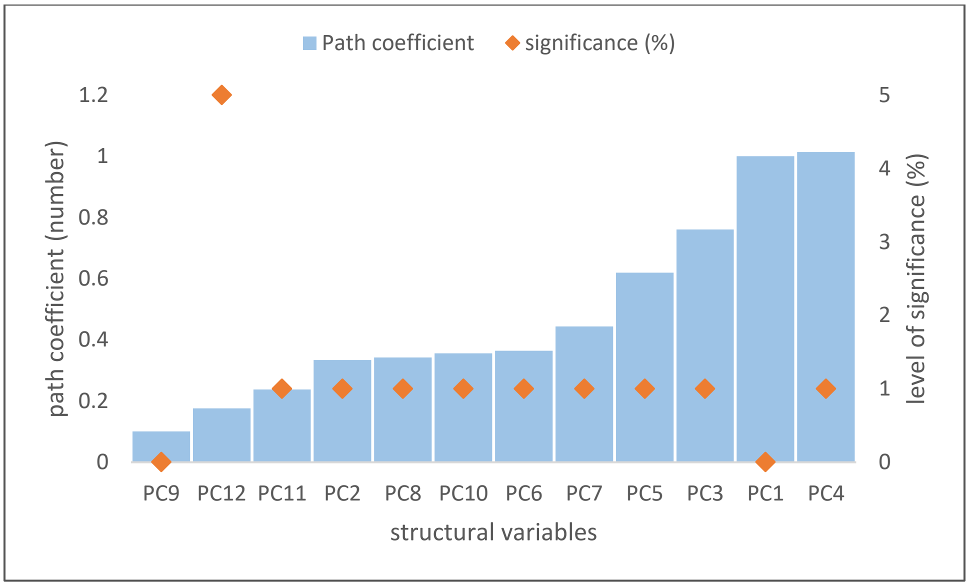



Figure 4. Determinants of sustained AFI adoption

Dependent variable sustained AFI adoption; model: structural equation model; number of obs=145, estimation method= ml, Log likelihood = -3258.2009, LR test of model vs. saturated: chi2(54) = 171.21, Prob > chi2 = 0.0000. ***, ** significant at 1% and 5% levels of significance.

'Observability' (PC1) is not a significant factor for farmers to form a long-term adoption intention (Figure 3) as most farmers are acquainted with the AFI already and, given their widespread occurrence, can easily observe their (under-)performance on fellow farmers' farms. 'Tasks & products' (PC9) is also insignificant because the workload and volume of tasks related to AFI adoption is relatively marginal. During discussions, farmers also asserted that AFI is a relatively low cost investment due to the marginal labor requirement except for purchasing seedlings, planting, and weeding in the first year. While generally, AFI are more preferred if they provide multiple products that diversify commercial options (such as charcoal, fuelwood, construction wood, furniture etc.), the provision of different products is not a critical feature for forming long-term adoption intentions as farmers often are driven by home consumption needs, as revealed during group discussions.

‘Production and marketing performance’ (PC4), ‘relative economic preference’ (PC3), ‘biological features and communicability’ (PC5), and ‘compatibility and substantial income’ (PC7) highly impact the formation of long-term adoption intentions. ‘Complementarity and competition with the existing production’ (PC6), ‘market preference and communicability’ (PC10), ‘complexity in production and harvesting’ (PC2), and related ‘social benefits’ (PC8) also influence such intentions. Likewise, the maturation period, environmental and labor demands are further factors associated with these intentions.

Overall, the findings in Figure 3 resemble the results of a cross-sectional adoption analysis. Despite being unable to show a temporal variation in the relationship between innovation attributes and adoption intention, the current inquiry provides a high-level overview of what factors drive long-term AFI adoption.

### 4.4. Discussion

Farmers from the three study districts evaluated the AFI on the nine innovation attributes. The average Likert scores of the AFI ranged from the lowest for risks related to eucalyptus growing (1.91) to the highest for the compatibility of acacia (5.24). On a combined innovation basis, observability (4.90) had the highest, and risk (2.06) had the lowest mean Likert value. Possession of low risk value positively supports farmers' adoption decisions.

Unlike the evaluation of the nine attributes in the descriptive analysis, appendix Table 2 revealed that only five attributes are suitable for PCA analysis. Based on PCA, 12 variables are produced and investigated on their relationship to actual adoption and adoption intention. The actual adoption proved that innovation attributes contribute 16-59% of the decision to adopt the AFI, largely confirming Rogers’ (2003) claim of 49-87% contribution to the overall adoption decision. The rest of the variance explanation may be attributed to household contexts and system level features (Amare and Darr 2020). However, a non-significant model for the second round of adoption highlighted that innovation attributes are not always central factors for making adoption decisions, indicating that decisions regarding expanding or discontinuing adoption are made based on earlier confirmatory experiences with the specific AFI.

Concerning the econometric models, attributes predominantly belonging to the relative advantage, complexity, performance, and observability constructs influenced adoption. The items related to observability significantly influenced AFI during first-round adoption. Observability or communicability features are desired and evaluated during the early stages of AFI adoption. This result indicates that if farmers can observe the features of the AFI, they are motivated to adopt the AFI in case it has desirable features (they may reject the AFI in case it possesses intolerably undesirable features). Alternatively, farmers are reluctant to adopt the AFI due to poor observability. Hence, for first-round adoption, development practitioners should deliver AFI with sound observability features. Evans (1988) reported increased AFI adoption rates in Paraguay from conducting demonstration plots, which improved the observability of the AFI. Farmers in Cambodia showed significantly positive adoption intentions for rhizobium innovations where farmers can observe performance under actual farm conditions (Farquharson et al., 2013). In contrast, a study on farmers in Java revealed that observability of the innovation had no significant influence on the adoption of integrated crop-livestock innovations (Purnomo et al. 2019). While it is intuitive that observing an innovation's performance motivates farmers' adoption or rejection decisions (Rogers 2003), finding the same direction of the relationship between an attribute and adoption across a range of innovations is unlikely (Vagnani and Volpe 2017). Divergent results are thus often seen as manifestations of context specificities.

In contrast, relative advantage, performance, compatibility, and complexity comprehensively influence decisions on AFI adoption, regardless of the round of adoption. In an agriculture related study, Farquharson et al. (2013) found a highly significant relationship between rhizobium adoption intention and the relative advantage of the innovation. Tokede et al. (2020) assessed farmers' perception of AFI on trialability, relative advantage, compatibility, and complexity factors. They found a high and significant correlation between AFI adoption and perception toward agroforestry, with positive perception leading to AFI adoption. Purnomo et al. (2019) found a significant relationship between adopting integrated crop-livestock innovations and the trialability and relative advantage attributes. However, complexity and compatibility were unrelated to the adoption of the innovations. A review by Tornatzky and Klein (1982) found that compatibility, relative advantage, and complexity have a consistent positive association with innovation adoption. Similarly, Vagnani and Volpe (2017) found parallel results for organizational innovations. Farmers in Ethiopia frequently retain AFI of indigenous origin on their farmers due to the relative advantages related to feeding, energy, and construction material provision (Amare et al. 2019).

Our results demonstrate that the various constructs do not affect adoption at a similar strength in a given round and at different rounds of adoption. The negative correlation of ‘production and marketing performance’ (PC4) to first-round AFI adoption can be related to farmers' learning process assessing the innovation (Dhakal and Rai 2020; Zeweld et al. 2017). Before adopting the AFI to exploit profitability opportunities, farmers assess the AFI concerning its adaptability, compatibility, and the risks associated with its adoption, such as the impact on food production and home consumption needs, market risks, and others. Hence, farmers might not be initially attracted by economic benefits alone but rather make judgments based on prevailing household needs and environmental contexts (Jara-Rojas et al., 2020). Adaptability and complexity also affect the adoption decision process and financial profitability, where less complex AFI requires marginal production and marketing arrangements, and highly adaptable AFI that are preferred. These aspects negatively influence ‘production and marketing performance’ on initial adoption. In contrast, ‘biological features and communicability’ (PC5) and ‘social benefits’ (PC8) positively correlate to adoption. Farmers hence consider the biological traits of the specific AFI in their adoption decisions (Amare et al. 2019). In terms of social benefits, being part of rural communities that are encircled by various norms, values, and mutual dependencies, farmers are attracted to adopt AFI that help them acquire greater social status (Nguyen et al. 2021; Qiu et al. 2021).

Table 3. Summary of relationships between innovation characteristics and AFI adoption

| Innovation characteristics | Temporal analysis | | | Cross-sectional analysis | | |
|---|---|---|---|---|---|---|
| | Positive | Negative | Non-significant | Positive | Negative | Non-significant |
| Relative advantage | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Observability | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Compatibility | | ✓ | ✓ | ✓ | | |
| Complexity | | ✓ | ✓ | ✓ | | ✓ |
| Performance | ✓ | ✓ | ✓ | ✓ | | |

Temporal analysis refers to the analysis of retrospective data over consecutive rounds of adoption decision-making; cross-sectional analysis refers to the aggregate analysis over a single adoption point; positive, negative non-significant refers to significance of associations between the respective AFI characteristics and the dependent AFI adoption variable.

Overall, the findings demonstrate that innovation attributes influence adoption decisions, which helps to strengthen classical adoption studies that mainly focus on household variables. However, as displayed in Table 3, the influence of the various innovation characteristics on AFI adoption is not unidirectional. As revealed during the temporal inquiry, the complex positive and negative association of a single innovation characteristic to AFI adoption can reflect changing influences on decision-making over time but also result from the combination of variables in principal components. Future research should, therefore, more carefully assess the impact of location or context-specific components in regression analysis. The results of the cross-sectional analysis indicate that except for observability and complexity and some features related to relative advantage, all innovation characteristics are positively related to AFI adoption. The non-significance of the observability and complexity variables is related to the high visibility and simple management of the three AFI. In contexts of intensive management for improved productivity and a larger amount of marketable products derived from the AFI, these variables might become significant, as confirmed by other researchers (Ofoegbu and Ifejika Speranza 2017). Simultaneously relative advantage is positively associated with AFI adoption, as revealed in the combined attributes represented under PC3, PC6, PC7, PC8, PC10, and PC11. While the PCA supported our understanding of factors influencing the adoption decision, it blurred the concrete variables and their direction to AFI adoption simultaneously. Among the five original Rogers attributes, trialability was excluded from the regression analysis due to PCA rules, and its impact on AFI adoption was considered marginal. We found that innovation performance was essential for making the adoption decision. The knowledge revealed by SEM in the cross-sectional assessment and the temporal assessments complemented each other. Specific attribute-based regression analysis is essential to acquire more insightful information on innovation characteristics influencing consecutive rounds of adoption.

Concerning our first research objective, our descriptive inquiry illustrates that farmers accredit the various innovation attributes related to specific AFI. A regression analysis revealed that these attributes play a significant role in the farmers' AFI adoption decisions. Hence, the proposition of the diffusion of innovations theory is endorsed. We also tested its validity for AFI. Regarding our third research objective, we found that all of the attributes proposed initially by Rogers (1983, 1995, 2003), but trialability, were significantly linked to AFI adoption, confirming the empirical validity of the theory for examining factors affecting the adoption of AFI. Previous classical economic and social science studies (Tafere and Nigussie 2018) that largely ignored the contribution of innovation attributes have thus, at best, contributed a partial view of AFI adoption.

Hence, properly incorporating these variables in future studies is obligatory to understand adoption influencing factors fully. Given that the limited number of attributes proposed by Rogers may potentially decrease the robustness of output from innovation attribute studies, we incorporated disinvestment, risks, performance, and volition as additional constructs. Of these, performance demonstrated statistical significance in our analyses, thereby illustrating the insufficiency of the initial five attributes proposed by Rogers. Therefore, we recommend that researchers rigorously incorporate this attribute in future studies and expand the list of innovation attributes in their investigations by carefully considering local context and the specific AFI.

Regarding our second research objective, the temporal analysis determined the time-specific importance of each attribute (Table 2). For example, observability was primarily linked to the first-time adoption decision and had no impact on subsequent decision cycles. In addition, we observed that innovation attributes might be less critical for follow-up adoption decisions. We, therefore, claim that temporal analysis of retrospective or panel data provides a more granular understanding of the adoption process. Amare and Darr (forthcoming) also found that examining the socioeconomic factors affecting sequential AFI adoption using retrospective data is more insightful than cross-sectional analysis.

While our study demonstrates the importance of innovation attributes in agriculture and AFI adoption, it is not without limitations. The lack of importance of the trialability attribute in our study may be an artefact of using PCA. Therefore, future research should further explore this attribute and its significance level in AFI adoption decisions. Further limitations include the inability to establish relationships between specific innovation characteristics and AFI adoption in a single round of adoption due to the mingling of items belonging to different attributes during PCA. Future research should therefore aim to explore a limited set of specific innovation characteristics to avoid the need for dimension reduction techniques. Finally, while we aimed to validate and triangulate the data during data collection with the utmost care, retrospective instead of true panel data may have reduced data reliability and validity due to recall and further biases.

## 5. Conclusion and implications

This study proved that attributes of an AFI contribute to the adoption decision making, and their importance varies over time. While our results partly confirm the importance of the five original attributes suggested by Rogers (2003), they also demonstrate that further innovation attributes guide the adoption decision for specific innovations. Specifically, we found that the inclusion of the performance attribute better explained adoption in the temporal and cross-sectional analyses. While a significant relationship with adoption could not be established for all of the newly introduced innovation attributes in our study, we encourage further research to extend Rogers' framework, given that the influence of such attributes is highly context specific. Likewise, research should be carried out to test alternative frameworks to explain innovation attributes' effect on adoption.

While our findings, in principle, also confirmed Rogers' proposition that the original five attributes explain 49-87% of the adoption decision, our results suggest a considerably lower proportion of the variance explained (16-59%). The proportion of unexplained variance in our model and the fact that innovation characteristics do not always influence farmers' AFI adoption decisions support the view that AFI adoption should be analyzed using a comprehensive systems perspective (Amare and Darr 2020). Further AFI adoption studies should therefore aim to include the influence of socioeconomic, psychological, and system-level variables next to innovation characteristics to approach a 100% variance explanation.

By employing a temporal analysis and analyzing long-term adoption intention, our study responded to calls for investigating the adoption process instead of the event alone. Our results document that some innovation attributes are key to AFI adoption decisions while others are not related to AFI adoption. Biological traits and marketing performance, compatibility, cash income, and social benefits are the most critical AFI attributes influencing adoption decisions. Their importance is partly time-specific across the adoption interval. Some innovation attributes ('biological feature and communicability' and 'social benefits') affected AFI adoption initially but not in all later rounds of adoption. Policymakers and development practitioners should therefore emphasize promoting AFI with desirable characteristics.

**Conflict of interest:** Authors declare no conflict of interest.

Supplementary file: Appendix D

## Publication bibliography

Adesina, A. (1993): Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. In *Agricultural Economics* 9 (4), pp. 297–311. DOI: 10.1016/0169-5150(93)90019-9.

Amare, Dagninet; Darr, Dietrich (forthcoming): Can a sequential analysis provide a more robust understanding of farmers' adoption decisions? An example from an agroforestry adoption study in Ethiopia. In *ECOLEC-D-22-01243*.

Amare, Dagninet; Darr, Dietrich (2020): Agroforestry adoption as a systems concept: A review. In *Forest Policy and Economics* 120, Article 102299. DOI: 10.1016/j.forpol.2020.102299.

Amare, Dagninet; Darr, Dietrich (2022): Farmers' Intentions towards Sustained Agroforestry Adoption: An Application of the Theory of Planned Behavior. In *Journal of Sustainable Forestry*. DOI: 10.1080/10549811.2022.2123358.

Amare, Dagninet; Mekuria, Wolde; T/wold, Tilaye; Belay, Beyene; Teshome, Akalu; Yitaferu, Birru et al. (2016): Perception of local community and the willingness to pay to restore church forests: the case of Dera district, northwestern Ethiopia. In *Forests, Trees and Livelihoods* 25 (3), pp. 173–186. DOI: 10.1080/14728028.2015.1133330.

Amare, Dagninet; Wondie, Menale; Mekuria, Wolde; Darr, Dietrich (2019): Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. In *Small-scale Forestry* 18 (1), pp. 39–56. DOI: 10.1007/s11842-018-9405-6.

Assaad, Ragui; Krafft, Caroline; Yassin, Shaimaa (2018): Comparing retrospective and panel data collection methods to assess labor market dynamics. In *IZA J Develop Migration* 8 (1). DOI: 10.1186/s40176-018-0125-7.

Basera, Clay Hutama; Dhliwayo, Kossam (2013): Impact of Product/Service Characteristics on the Rate of Adoption of an Innovation. A case of Eco Cash mobile services in Chipinge District, Zimbabwe. In *IOSR Journal of Business and Management* 13 (6), pp. 26–32.

Carrington, Peter J.; Scott, John; Wasserman, Stanley (Eds.) (2012): Models and Methods in Social Network Analysis: Cambridge University Press.

Cochran, W. G. (1963): Sampling Techniques. 2nd. New York: John Wiley and Sons, Inc.

Dhakal, Arun; Rai, Rajesh Kumar (2020): Who Adopts Agroforestry in a Subsistence Economy?—Lessons from the Terai of Nepal. In *Forests* 11 (5), p. 565. DOI: 10.3390/f11050565.

Eiamkanchanalai, S.; Assarut, N. (2012): Effects of Innovation Characteristics and Emotional Attachment on Adoption of the Digital Magazine. Available online at https://pdfs.semanticscholar.org/5b31/0c3e1aa5e94b208af376aca6abe52bd75b88.pdf, checked on 3/10/2020.

Evans, Patrick T. (1988): Designing agroforestry innovations to increase their adoptability: a case study from Paraguay. In *Journal of Rural Studies* 4 (1), pp. 45–55. DOI: 10.1016/0743-0167(88)90078-2.

Farquharson, Robert J.; Martin, Robert J.; Mccorkell, Bruce; Scott, J. Fiona; Sotheary, El; Phaloeun, Chan et al. (2013): Characteristics of an Agricultural Innovation and Incentives for Adoption: Rhizobium in Cambodia. In *International Journal of Environmental and Rural Development* 4-2, 44-49.

Flight, Richard L.; D'Souza, Giles; Allaway, Arthur W. (2011): Characteristics-based innovation adoption: scale and model validation. In *Jnl of Product & Brand Mgt* 20 (5), pp. 343–355. DOI: 10.1108/10610421111157874.

Gandasari, Dyah (2021): Analysis of Innovation Attributes in The Innovation Adoption of Agricultural Mechanization Technology in Farmers. In *Jurnal KMP* 19 (01), pp. 38–51. DOI: 10.46937/19202132705.

Gibson, John; Kim, Bonggeun (2005): Can we trust retrospective recall to replace panel data? Available online at https://www.researchgate.net/publication/228431326.

Jara-Rojas, Roberto; Russy, Soraya; Roco, Lisandro; Fleming-Muñoz, David; Engler, Alejandra (2020): Factors Affecting the Adoption of Agroforestry Practices: Insights from Silvopastoral Systems of Colombia. In *Forests* 11 (6), p. 648. DOI: 10.3390/f11060648.

Jolliffe, Ian T.; Cadima, Jorge (2016): Principal component analysis: a review and recent developments. In *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences* 374 (2065), p. 20150202. DOI: 10.1098/rsta.2015.0202.

Kansanga, Moses Mosonsieyiri; Luginaah, Isaac; Bezner Kerr, Rachel; Dakishoni, Laifolo; Lupafya, Esther (2021): Determinants of smallholder farmers' adoption of short-term and long-term sustainable land management practices. In *Renew. Agric. Food Syst.* 36 (3), pp. 265–277. DOI: 10.1017/S1742170520000289.

Kapoor, Kaur Kawaljeet; K. Dwivedi, Yogesh; D. Williams, Michael (2014): Innovation adoption attributes: a review and synthesis of research findings. In *Euro Jrnl of Inn Mnagmnt* 17 (3), pp. 327–348. DOI: 10.1108/EJIM-08-2012-0083.

Kapoor, Kawaljeet; Dwivedi, Yogesh K.; Williams, Michael D. (2013): Role of Innovation Attributes in Explaining the Adoption Intention for the Interbank Mobile Payment Service in an Indian Context. In Yogesh K. Dwivedi, Helle Zinner Henriksen, David Wastell, Rahul De' (Eds.): Grand Successes and Failures in IT: Public and Private Sectors. IFIP WG 8. 6 International Conference on Transfer and Diffusion of IT, TDIT 2013, Bangalore, India, June 27-29, 2013, Proceedings, vol. 402. New York: Springer (IFIP Advances in Information and Communication Technology Ser, 402), pp. 203–220.

Kebede, Bereket; Zizzo, Daniel John (2015): Social Preferences and Agricultural Innovation: An Experimental Case Study from Ethiopia. In *World Development* 67, pp. 267–280. DOI: 10.1016/j.worlddev.2014.10.022.

Le Hoang Nguyen, Long; Halibas, Alrence; Quang Nguyen, Trung (2022): Determinants of precision agriculture technology adoption in developing countries: a review. In *Journal of Crop Improvement*, pp. 1–24. DOI: 10.1080/15427528.2022.2080784.

Miller, Rebecca L. (2015): Rogers' Innovation Diffusion Theory (1962, 1995). In Mohammed Nasser Al-Suqri, Ali Saif Al-Aufi (Eds.): Information seeking behavior and technology adoption. Theories and trends, Vol. 15. Hershey, PA: Information Science Reference (Advances in knowledge, acquisition, transfer, and management book series), pp. 261–274.

Miriti, Philip; Regassa, Mekdim D.; Ojiewo, Chris O.; Melesse, Mequanint B. (2022): Farmers' preferences and willingness to pay for traits of sorghum varieties: Informing product development and breeding programs in Tanzania. In *Journal of Crop Improvement*, pp. 1–20. DOI: 10.1080/15427528.2022.2079038.

Nguyen, Mai Phuong; Pagella, Tim; Catacutan, Delia C.; Nguyen, Tan Quang; Sinclair, Fergus (2021): Adoption of Agroforestry in Northwest Viet Nam: What Roles Do Social and Cultural Norms Play? In *Forests* 12 (4), p. 493. DOI: 10.3390/f12040493.

Oca Munguia, Oscar Montes; Llewellyn, Rick (2020): The Adopters versus the Technology: Which Matters More when Predicting or Explaining Adoption? In *Applied Economic Perspectives and Policy* 42 (1), pp. 80–91. DOI: 10.1002/aepp.13007.

Ofoegbu, Chidiebere; Ifejika Speranza, Chinwe (2017): Assessing rural peoples' intention to adopt sustainable forest use and management practices in South Africa. In *Journal of Sustainable Forestry* 36 (7), pp. 729–746. DOI: 10.1080/10549811.2017.1365612.

Purnomo, Sutrisno Hadi; Handayanta, Eka; Hanifa, Aqni; Wibowo, Agung; Purnaningrum, Mela (2019): The Influence of Innovation Characteristics to Farmers' Decision in Accepting Integrated Crop-Livestock Technology in Karanganyar Region, Central Java. In *BuletinPeternak* 43 (4). DOI: 10.21059/buletinpeternak.v43i4.40765.

Qiu, Wenwen; Zhong, Zhangbao; Huang, Ya (2021): Impact of perceived social norms on farmers' behavior of cultivated land protection: an empirical analysis based on mediating effect model. In *International Journal of Low-Carbon Technologies* 16 (1), pp. 114–124. DOI: 10.1093/ijlct/ctaa043.

Reed, M. S. (2007): Participatory technology development for agroforestry extension: an innovation-decision approach. In *African Journal of Agricultural Research* 2 (8), pp. 334–341.

Rogers, E. M. (1983): Diffusion of Innovations. 3rd. New York: The Free Press.

Rogers, E. M. (1995): Diffusion of Innovations. 4th. New York: The Free Press.

Rogers, E. M. (2003): Diffusion of Innovations. 5th. New York: The Free Press.

Scott, Shannon D.; Plotnikoff, Ronald C.; Karunamuni, Nandini; Bize, Raphaël; Rodgers, Wendy (2008): Factors influencing the adoption of an innovation: an examination of the uptake of the Canadian Heart Health Kit (HHK). In *Implementation science : IS* 3, p. 41. DOI: 10.1186/1748-5908-3-41.

Senyolo, Mmapatla Precious; Long, Thomas B.; Blok, Vincent; Omta, Onno (2018): How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa. In *Journal of Cleaner Production* 172, pp. 3825–3840. DOI: 10.1016/j.jclepro.2017.06.019.

Shiksha, Krishi (2022): Introductory Agroforestry: Desirable Characteristics for Agroforestry (AGF311). Available online at http://ecoursesonline.iasri.res.in/mod/page/view.php?id=14511.

Tafere, Solomon Mulu; Nigussie, Zebene Asfaw (2018): The adoption of introduced agroforestry innovations: determinants of a high adoption rate – a case-study from Ethiopia. In *Forests, Trees and Livelihoods* 27 (3), pp. 175–194. DOI: 10.1080/14728028.2018.1493954.

Tokede, A. M.; Banjo, A. A.; Ahmad, A. O.; Akanni, O. F.; Olumide-Ojo, O. (2020): PERCEPTION OF FARMERS ON AGROFORESTRY SYSTEMS ADOPTION IN AKINYELE LOCAL GOVERNMENT AREA, IBADAN, OYO STATE, NIGERIA. In *Journal of Research in Forestry, Wildlife & Environment* 12 (3), pp. 235–242.

Tornatzky, Louis G.; Klein, Katherine J. (1982): Innovation characteristics and innovation adoption-implementation: A meta-analysis of findings. In *IEEE Trans. Eng. Manage.* EM-29 (1), pp. 28–45. DOI: 10.1109/TEM.1982.6447463.

Umar, Bridget Bwalya (2014): A critical review and re-assessment of theories of smallholder decision-making: a case of conservation agriculture households, Zambia. In *Renew. Agric. Food Syst.* 29 (3), pp. 277–290. DOI: 10.1017/S1742170513000148.

Vagnani, Gianluca; Volpe, Loredana (2017): Innovation attributes and managers' decisions about the adoption of innovations in organizations: A meta-analytical review. In *International Journal of Innovation Studies* 1 (2), pp. 107–133. DOI: 10.1016/j.ijis.2017.10.001.

Wani, Tahir Ahmad; Ali, Syed Wajid (2015): Innovation Diffusion Theory. Review & Scope in the Study of Adoption of Smartphones in India. In *Journal of General Management Research* 3 (2), pp. 101–118.

Wendorf, Craig A. (2002): Comparisons of Structural Equation Modeling and Hierarchical Linear Modeling Approaches to Couples' Data. In *Structural Equation Modeling: A Multidisciplinary Journal* 9 (1), pp. 126–140. DOI: 10.1207/S15328007SEM0901_7.

Windsor, Fredric M.; Armenteras, Dolors; Assis, Ana Paula A.; Astegiano, Julia; Santana, Pamela C.; Cagnolo, Luciano et al. (2022): Network science: Applications for sustainable agroecosystems and food security. In *Perspectives in Ecology and Conservation* 20 (2), pp. 79–90. DOI: 10.1016/j.pecon.2022.03.001.

Zeweld, Woldegebrial; van Huylenbroeck, Guido; Tesfay, Girmay; Speelman, Stijn (2017): Smallholder farmers' Behavioral intentions towards sustainable agricultural practices. In *Journal of environmental management* 187, pp. 71–81. DOI: 10.1016/j.jenvman.2016.11.014.

## 4.5. Influence of system level factors on adoption of agroforestry innovations

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**Abstract**

System level features, services offered by institutions, aimed at promoting the improvement of livelihoods through the adoption of innovations have been central to the success of extensive innovation adoptions in developed and developing nations. Despite steady efforts, adopting agroforestry innovations (AFI) in developing nations is marginal. In addition to farmer specific contexts, the importance of system level features relating to extension, credit, policy, marketing, and risk factors are vital for the nominal adoption rate. In this study, we explicitly examine the influence of system level features on the adoption of three AFI under smallholder contexts. We employ retrospective data unfolding the adoption decision of 327 smallholders spanning three consecutive adoption decisions. Findings revealed that the importance of system level features increases over time when farmers make follow-up adoptions or when diffusion occurs at a grander scale. This is essentially related to the marketing orientation of farmers, which requires the facilitation of market opportunities, investment capital, reduction of risks associated with markets, and formulation and implementation of working policy regulations. Production based risks are relevant only at the initial adoption stage, and their importance diminishes as farmers continue to make follow-up AFI adoptions past first time adoption. The absence of a relation between extension services and with AFI adoption decision of smallholders indicates either AFI are not adequately addressed by extension services or current extension services fundamentally focus on traditional crop production and elude AFI sectors. And in the eucalyptus AFI system, extension advisory experts openly discourage adoption. Overall, system level features explained 26%-44% of the variance in the AFI adoption decision of the farmers.

**Keywords:** agroforestry, Ethiopia, institutional, SUREG, risk factors, thematic

## 1. Introduction

Adoption of innovations particularly agricultural innovations in the developing world, is largely driven by efforts of government and non-governmental organizations (Feder et al. 1985; Wordofa et al. 2021). Such activities as input delivery, provision of training, credit facilitation, designing legal frameworks, and marketing related activities are the main deeds these organizations undertake in order to facilitate the development, diffusion, and adoption of different agricultural technologies aimed at fulfilling the development needs of societies (Amare and Darr 2020; Mercer 2004; Nabaasa et al. 2022; Issa and Kagbu 2017). AFI is one of the components of these agricultural innovations that organizations have addressed as a development target. Attempts were made to identify the factors affecting AFI adoption (check the list of studies reviewed by Amare et al. 2019; Amare and Darr 2020).

Amare and Darr (2020) reviewed adoption studies in agroforestry (AF). They found that system level factors are one of the three major factors influencing farmers' decision whether or not to adopt. Authors (Mercer 2004; Montambault and Alavalapati 2005) have also proved the importance of these factors for extensive AFI adoption and diffusion. Studies have employed some or few system level features in their content analysis and econometric models (Mendelson et al. 2021). The system level factors affecting AFI adoption are incorporated in these studies as part of a broader undefined set of factors and largely in combination with socioeconomic variables (Abiyu et al. 2016), various defined groups of factors such as market and risk elements (Basinger et al. 2012), local institutional factors (Binam et al. 2017; Zerihun 2020) and as government roles (Amare et al. 2019). Rarely (Zerihun 2020) have these factors been discretely investigated, to the best of our knowledge, when assessing adoption studies related to AFI. Discrete investigation of these factors eludes confounding effects with other variables and assists in-depth understanding of their specific influence on AFI adoption. Besides, there is a shortage of studies that employed longitudinal data while investigating system level features' effect on AFI adoption. In this study, we explicitly focus on the effect of system level features that affect AFI adoption using retrospective data.

Despite a diversity of nomenclature such as institutional, structural, system level, organizational level factors, and governmental role, we call these factors related to the roles of organizations and governments beyond the capacity of smallholder farmers 'system level features'. System level features comprise the technology delivery mechanism, market management (input and output), policy and regulations, and stakeholders involved in the AFI development-diffusion continuum (Amare and Darr 2020). This study, therefore, aims at exploring the temporal effect of system level features on AFI woodlots adoption using a retrospective survey. The innovativeness of this paper is accredited to (1) discrete inquiry of system level features alone, excluding other categories of factors such as psychological (Amare and Darr 2022) or socioeconomic (Amare and Darr forthcomingb), or innovation characteristics (Amare and Darr forthcominga), relating to AFI adoption, (2) comprehensive inquiry of the complete set of system level features relating to AFI adoption, (3) employment of process analysis as incremental adoption changes are explored using retrospective information, and (4) insightful incorporation of risk factors by developing aggregated risk indexes.

## 2. Analytical framework

The diffusion of innovations (Rogers 1983) has been and continues to be the principal theoretical model for the study of the adoption of various innovations. Diffusion of innovation theory (DOI) states that the rate of adoption is influenced by perceived attributes of the innovation (innovation characteristics), type of innovation decision (i.e., either optional, collective, or authoritative decisions), communication channels, nature of social system and efforts of change agents (Rogers 2003, 1983). Whether exploring the factors at the social system, the innovation level, or the adopters, DOI has been frequently employed as a legitimate theory to explain the contexts affecting the adoption and diffusion of innovations across sectors and regions, and it has been the leading adoption theory and theoretical framework in agriculture adoption research (Straub 2009; Douthwaite and Hoffecker 2017). In AF, DOI concepts are often intermingled with traditional economics studies and are chaotically employed to identify socioeconomic factors affecting the adoption of farmland, home garden, and other forms of AF (Amare et al. 2019; Abiyu et al. 2016; Bantihun Mehari and Abera 2019). Due to this hectic exploration, results from adoption research have marginally been incorporated in the ongoing policy design and development interventions, as proved by the absence of a change of development courses or direction.

Consequently, Amare and Darr (2020) developed a comprehensive adoption framework, named the 'AFI adoption analytical framework', that better explains the contexts by which smallholder farmers make AFI adoption decisions. In this analytical framework, system level features comprising credit, institution, input-output markets, and advisory services are stated as one of the three major categories of variables influencing adoption, combined with other groups of variables or distinctly by themselves. Despite appreciating following the systems perspective and exploring all of the contexts, it is necessary to investigate the role of system level features (i.e., discretely) on AFI adoption of smallholder farmers to comprehend better their typical contribution to the overall AFI adoption decision. By borrowing the concepts from this analytical framework, we developed the below (Figure 1) contextualized analytical framework depicting the relationship between system level features and their influence on smallholder farmers' AFI adoption decisions.

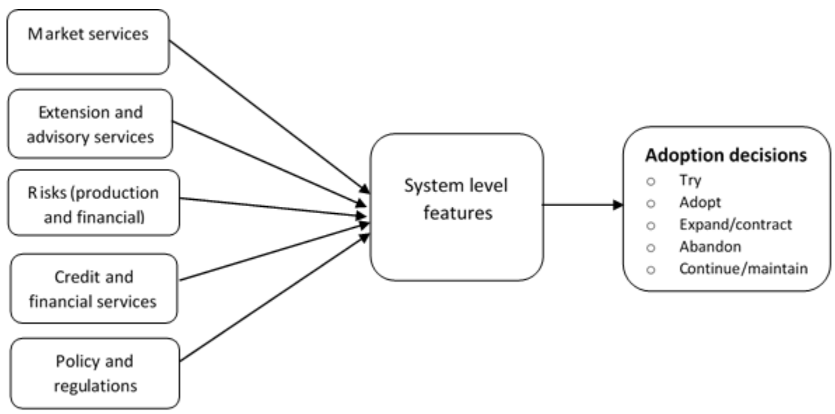


Figure 5. Relationship between system level features and AFI adoption decision of smallholder farmers

Therefore, this study employs Figure 1 as the analytical framework for inquiry about the statistical association of system level features on the adoption of AFI. The research focuses on the functions fulfilling these variables, and hence the study evades detailing the names and types of institutions that fulfilled these functions. From the perspective of the roles and responsibilities of the different institutions, it is possible and advised to undertake stakeholder or actor-network analysis. Eventually, we explored how this list of system level features influences AFI adoption of the smallholders in three districts of the Amhara region of Ethiopia, representing the larger smallholder population of the developing world, particularly sub-Saharan Africa.

## 3. Research methods

This research is conducted in the Amhara region of Ethiopia. The Amhara region is located (9°-14° N and 36°-40°E) in North West Ethiopia (Amare et al. 2017; Amare et al. 2016). Mecha, Fagita Lekoma, and Banja are the study locations selected from the region. The three AFI systems, acacia, bamboo, and eucalyptus, are the focus of this research. The AFI systems are selected purposively due to the intensive production and involvement of diverse stakeholders addressing various system-level features at different contexts or stages of adoption and/or production and marketing (Amare and Darr forthcomingb, 2022). A multistage sampling procedure is followed for data collection. Using a simple random sampling method, data from 327 households is collected. Data collection tools contained both close and open ended questions. Three focus group discussions and nine key informant interviews are also conducted to enrich the household data collected from the survey. Additional information is collected from informal discussions with farmers and experts of the bureau of agriculture.

Data management for system level features began with topic coding, category (themes) building, and index development for risk factors. We at first differentiated the diverse types of risks related to marketing, policy, production, and finance into various categories based on the resemblance of the list of risk factors. Afterward, we aggregated and developed an index for each risk factor. For example, for developing production risk, we first classified the list of production risks specified by farmers into five differentiating categories: frost, intermittent rainfall, local climate variability, drought, and pests. Then we created two types of indicators (i) production risk (1 if the farmer responded yes to any of the production risks associated with the specific AFI production, 0 otherwise or if the farmer stated that there was no kind of production risk associated with the production of the specific AFI), and (ii) production risk intensity (i.e., the mean perceived Likert value of the respondents replies to any of the production risk classes described above). Production risk intensity ranged from the maximum Likert value of 5 to the minimum of 0 (i.e., if the farmer has not indicated any of the risks). All the other risk factors also followed a similar pattern of index development. Accordingly, marketing risk consisted of six categories: poor demand, distance to market, trust and relationship (density) with brokers and vendors, few alternative products, declining price due to glut production, and small and or extended value chain. Likewise, financial risk (i.e., poor financial system, capital shortage, and delayed cash transfer) and policy risks (i.e., lack of policy focus, poor policy, and stiff policy) comprised three categories each.

Ultimately data is analyzed by employing content analysis, descriptive statistics, and econometric models to investigate the system level features affecting AFI adoption across adoption rounds. By descriptive statistics, we used statistical values (t-test) if the system level features differ across AFI systems. Analysis of the results of this study mainly employed qualitative content analysis. By content analysis, we tried to narrate, explore and triangulate the different system level features of the specified AFI to render insightful information.

Regarding econometric models, we examined how farmers' decision varies across time by considering their three consecutive (rounds) adoption decisions. The seemingly unrelated regression equation (SUREG) is employed for the time variant adoption inquiry. SUREG is employed when the error terms of two (and more than two) equations are correlated (McDowell 2004). Despite the possibility of specifying the three-round adoption decisions separately, the error terms might be correlated due to contemporaneous factors. Outcomes of the extent of second and third round adoption decisions might be dependent upon the decisions of the prior initial and second round adoptions, respectively. As a result, the error terms might correlate (Kim and Cho 2019). To account for such possible correlations, we employ the SUREG model to estimate the extent of AFI adoption and determine whether the error terms of the three adoption decision functions are correlated using the Breusch_Pagan test of independence (Acharya 2018; Zellner 1962).

Additionally, we anticipated that some variables are important for initial adoption but not for successive second and third round adoption decisions. For example, awareness creation (i.e., in terms of training and field visits) and adaptation based risks such as production risks (e.g., susceptibility to drought, pests, and intermittent rainfall) might be important for making initial adoption. Nevertheless, when farmers have already proved that the innovations are locally adapted and resistant to local climatic conditions, the importance of these factors progressively diminishes. In contrast, as these AFI are mainly market oriented productions, factors related to the availability of investment capital (i.e., for large scale adoptions) and market related issues or financial risks become prevalent after initial adoption. Accordingly, we employed SUREG to determine if the stated variables are influential for making adoption decisions throughout adoption decision making rounds.

## 4. Results

### 4.1.Descriptive summary

The farmers spent roughly 26 years on farming operations as their main occupation. Bamboo (30± 1.50) followed by eucalyptus (25.7±1.1) and acacia (23.65±1.45) AFI producers have the highest and lowest farming experience. Similar to their farming experience, bamboo AFI producing farmers (20.2±1.55), followed by eucalyptus (10.7±0.71) and acacia (5.18±0.29) producers, have the highest and lowest AFI production experience. On average, the farmers have nearly 12 years of experience AFI production. Intercropping at first (trial) adoption builds confidence to deter or evade any risks related to adaptability and market factors. It also consolidates the possibility of removing the AFI if uprooting is needed or farmers seek alternative enterprises. Nearly 57% of farmers practiced intercropping (i.e., intercropping of AFI with crops during establishment) of AFI woodlots during initial establishment. The intercrops revealed during discussions are non-root crop types to avoid uprooting during harvesting. Among AFI inter-croppers, 31.88% and 24.5% are from acacia and eucalyptus AFI production systems. Just 0.34% of the farmers' bamboo producers attempted bamboo AFI intercropping with some crops during the establishment year.

### 4.2.Key system level features

Based on the survey results, we identified infrastructure related to roads and public service centers, extension advisory services, training and field visits, credit, market, policy regulations, and risks as the principal system level features. Below, we discuss these essential system level features that mainly relate to AFI woodlots in our study area.

#### 4.2.1. Infrastructure

The two main infrastructures for the farming community are local public service centers and roads. Local public centers comprise the office of agriculture, Kebele administration, security offices, and health centers. Roads pertain to access to potential markets (i.e., input-output exchange capacity) or access to other potential services such as agricultural inputs, high end markets, and higher level health and administrative centers. Below we discuss the vicinity of these centers.

**Public service centers:** Due to the government's intention to provide public services in a single hub, almost all public service centers of the government are geographically congregated in one compound, adjacently placed to each other. At the lowest political administration of the country, at the Kebele level, all public or government sector offices are congregated for easy access or facilitation of farmers' productivity. Essential services comprising agriculture, land administration, security, environmental subjects, health, credit facilitation, and reimbursement or repayment are accessed easily by farmers.

On average, the farmers reside around a 2.33km radius of the Kebele administration. Recognizing the conventional travel speed of farmers (i.e., 7km per hour), these farmers reside within a 20min radius to the public service centers. Such close location of the service centers facilitates farmers' productivity as the transaction costs of retrieving the basic and regular services become marginal. Service delivery speeds depend on the expertise and personal behavior of experts. Amid farmers' proximity to the service centers, there exists a difference in the time traveling between the AFI systems' farmers to the service centers. Bamboo AFI producing farmers have a relatively intermediate vicinity to the public service centers. Acacia and eucalyptus AFI producing farmers comparably travel the longest and shortest distance to arrive at the service centers (Figure 2).

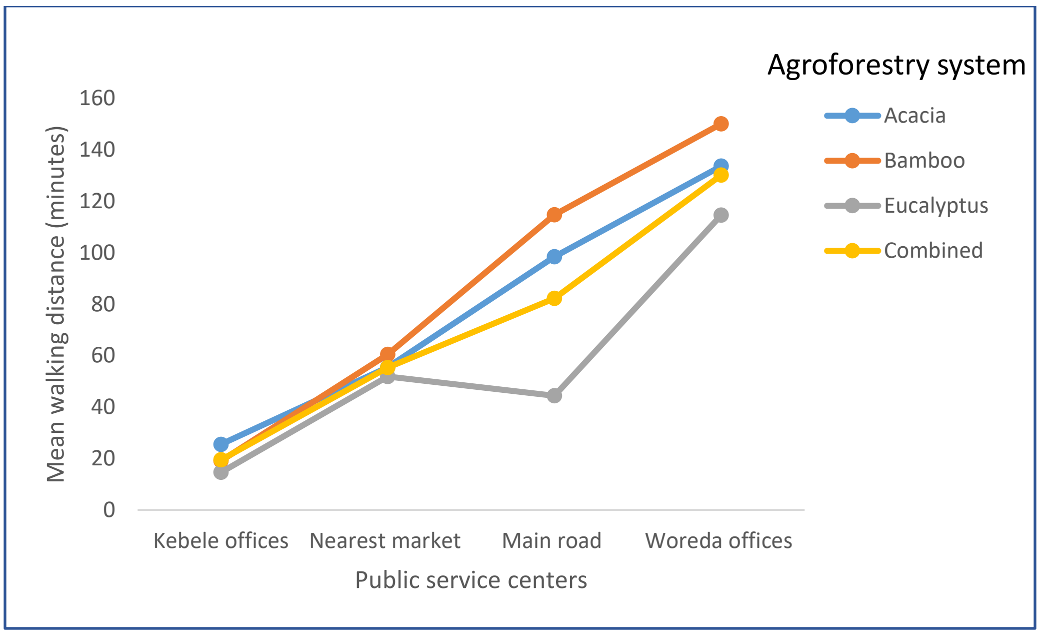

Figure 6. The proximity of farmers to essential public service centers

Regularly farmers take issues that are not usually solved or performed by Kebele offices to the Woreda offices. The proximity of these offices is linked highly to transport and accommodation based transaction costs. Additionally, travel to Woreda offices results in spillover effects on farm productivity as farmers have to travel and wait for a prolonged time until the issue is processed. As revealed during the discussion with farmers, the lengthy and sluggish performance at these offices delays the full-heart return of farmers to their farm operations. Such delayed issue processing at the offices moderates the productivity of farmers. On average, the farmers travel more than 15 km to the Woreda offices.

**Roads:** Regarding main roads, farmers must travel a minimum of 1 min and a maximum of 6hrs. On average, eucalyptus AFI producing farmers travel comparably less (less than 1hr) to reach the main asphalt road. The relative closeness of eucalyptus producers to the highway facilitates access to vehicles for transporting humans and commodities and creates a potential market for their products. In contrast, bamboo AFI producing farmers travel relatively longer hours (≈2hrs) to access the highway. Acacia producers, however, travel an intermediate distance (1.64 hours) to the highway, compared to both bamboo and eucalyptus producers. Contrary to their intermediary distance to the highway, one farmer resides farther away. The residential location of this farmer is as much as 6 and 3 times the average travel time of eucalyptus and bamboo AFI producing farmers, respectively. Bamboo producers, however, have relatively poor access to the main road and limited market opportunities associated with road access.

### 4.2.2. Extension advisory service

Government extension service is the dominant advisory service provision method for farmers on farm production and marketing in Ethiopia. Virtually 40% of the farmers have had extension service at least once in the past 5 years. In descending order, acacia (45.79%), bamboo (43.18%), and eucalyptus (32.58%) producers received extension services related to general agriculture operations, including production and marketing.

Nearly 42% of the farmers had extension contact in the immediate previous production year (i.e., preceding the 2019 production year where data is collected). Among these beneficiaries, 13.46%, 12.54%, and 16.21% are from acacia, bamboo, and eucalyptus AFI system. The frequency of extension contact in the previous production year is the highest for eucalyptus (3.4±0.33), followed by acacia (3.32±0.72) and the lowest for bamboo (3.25±0.36) producing farmers. On average, the farmers had more than 3 contacts per year (3.33±0.27). The contents of the extension service are diverse and mainly focused on traditional crop production (Table 1).

Even if extension agents continue to deliver important advisory services, their importance and contact frequency is increasingly declining, as revealed during a discussion with farmers and experts. The disconnection between farmers and development agents is accrued to the absence of fresh technical support from the experts' side.

Table 1. Content of extension advisory services

| | Focus | Difference among innovations |
|---|---|---|
| **General extension** | The motto is 'change yourself' and focuses on general agricultural activities; delivery of seasonal information, encouraging farmers' efforts, plantation of AFI on border plots, defocusing on AFI production | For traditional crop production and acacia trees, advise production of AFI on marginal lands. 14.37% of the farmers accessed general extension services. |
| **Improved management** | Sowing during appropriate seasons, row planting, spacing among plants, weeding, diseases management, fertilization | Not much extension on bamboo as it has been known for a long; development agents discourage eucalyptus production but in 2016 recommended harvesting techniques. This is the dominant extension service and was accessed by 22.32% of the farmers. |
| **Marketing** | Purchase of inputs, market information for products or demanded agricultural products, estimation of acacia production volume for tax and transport allowance purpose | Before harvesting, matured acacia plots productivity is valued to process tax collection and deliver transport permission license. Market information is generally provided for other farm products. 2.75% acquired market related extension service. |
| **Adoption of innovations** | Advisory on the need to use new innovations, and delivery of them such as improved seeds or cultivars (i.e., crops and coffee) | Mainly for crop production and marginally for bamboo species (Chinese species); discourage acacia plantation on fertile plots. 6.42% of the farmers got extension advisory on new innovations. |
| **Compost making** | Use of locally available resources for compost making to reduce cost of artificial fertilizer | Essentially for traditional crop production. |
| **Transplanting** | Suggested transfer of root-stocks afterwards matured propagation for good performance | Only bamboo producers (transfer of rootstock) |
| **Irrigation** | Vegetables, coffee and other homestead crops production | AFI are not recommended in irrigated areas |
| **Natural resources management** | Implementing natural resource management activities | Implementation of activities such as terraces, water harvesting structures. Discourage eucalyptus production due to acidic effect on soil and its contribution for degradation |

Source: own survey (2019)

Farmers also possess rich experience in local production contexts. Both of these contexts bring (i) a poor desire for extension services by farmers and (ii) unwanted feelings from the experts' side due to poor acceptance by farmers. In the case of increasing AFI production, the experts have no subject or have run out of advisory business services to contact farmers. In the face of such contexts, the interaction between farmers and development agents starts detaching. Farmers (hh. no. 313 and 315) from the eucalyptus AFI farming system confirmed this fact by revealing that they 'do not often meet with development agents as everyone has planted their plot with eucalyptus'. Other farmers (hh. no. 317) ascribed the preceding existence of strong contact with experts when delivering innovations, which is not the case currently. Overall, public service in the perspective of AFI is poor as lack of focus could be another logic behind this fact.

#### 4.2.3. Training

Minority (8.26%) of the farmers attended training on various agricultural issues. Most (5.50%) of these training beneficiaries are from the acacia AFI system. Bamboo (1.53%) and eucalyptus (1.22%) AFI producing farmers also benefited from diverse training. General awareness creation (i.e., orientation training) on farm production, AFI production, seedling preparation, fertilizer utilization, and row planting are the topics of the various training sessions.

#### 4.2.4. Field days on AFI

A smaller proportion (6.73%) of the farmers had participated in field days in the previous five years. Among them, 3.06% (each) are farmers from acacia and bamboo producing farming systems. A mere 0.61% of the field day participants are from eucalyptus AFI producing farming systems. Table 2 displays the purposes of the field days.

Table 2. Purpose of field days

| Purpose | AFI system |
|---|---|
| General awareness creation on the production and benefits of producing the innovations | Acacia, bamboo |
| Seedling preparation, row planting, seed rate, plot orientation, and harvesting | Acacia, bamboo |
| Demonstration of new innovation (Chinese bamboo) | Bamboo |
| Testimony of a beneficiary on how he benefited from charcoal vending | Acacia |

#### 4.2.5. Experimentation or modification

As a substitute or continuation of various extension services, training, field days, market feedback, and their own experience, farmers likely modify any of the inputs received initially. Virtually 5% of the farmers made modifications to AFI production. Most of these modifications are accomplished in the acacia (2.45%) farming system, followed by bamboo (1.53%) producers. A small percentage of eucalyptus (0.61%) AFI producing farmers engaged in modifying the inputs. The modifications comprise adjusting tree density based on market and neighbor feedback, row spacing, and management practices such as manuring and fertilization. The modification, specifically on acacia and bamboo, is linked to the general orientation of the extension advisory service for these AFI. Development agents provide comparably better advisory services for acacia and bamboo production preceded by traditional crop production. In the case of eucalyptus, there is a shortage of such services, which often discourages its adoption. With the absence of new technical support, farmers marginally experiment with their AFI production unless desired or requested by the market.

### 4.2.6. Credit

In the last ten years, 30% of the farmers accessed credit from different institutions. Larger and smaller proportions of farmers (27.52%) and (1.53%) accessed credit from ACSI and relatives, respectively. Just 0.61% of farmers (each) accessed credit from Edir and cooperatives, respectively. Credit for AFI production was accessed by 4.28% out of the 99 farmers who accessed credit (Table 3). The majority of these AFI productions targeted borrowers are from acacia AFI (3.98 %), whereas a smaller proportion are from bamboo (0.31%) AFI system. Nevertheless, no one from the eucalyptus production system borrowed cash to produce eucalyptus AFI. This could be attributed to the better-off context of eucalyptus producers compared to the other AFI producing farmers. Farmers from the eucalyptus AFI system have better productivity than traditional crops.

Table 3. Intended purpose of credit

| Intended purpose | Explanations | Percent (%) |
|---|---|---|
| Cattle purchase | Livestock purchase for breeding and farm activities | 10.26 |
| Land rent | Payment to farmers for renting-in land | 2.56 |
| Fattening | Purchase of sheep and bulls for fattening | 23.08 |
| Educational payment | Cash remittance for children studying remotely | 3.85 |
| Wage | Payment for daily laborers working in AF and farm activities | 5.13 |
| Draft power | Procurement of draft sources such as oxen and horse | 24.36 |
| House construction | Building new houses | 8.97 |
| AFI | Purchase of inputs and charcoal making | 11.56 |
| Petty trade | Local brew production and vending | 2.56 |
| Credit repayment | Paying back previously borrowed money | 1.28 |
| Apiculture | Purchasing beehives for beekeeping | 1.28 |
| Farm inputs | Procurement of fertilizer | 1.28 |
| Miscellaneous | Satisfying immediate needs, holiday celebrations and legal costs | 3.85 |

With better productivity and production, these farmers marginally need cash for neither establishing nor managing and harvesting AFI. Also, the recurring cash availability from crop production consolidates these farmers' position of eluding credit desire for their AFI production. The negligible number of farmers who accessed credit for eucalyptus AFI production might be due to the government's discouragement of its adoption. Paradoxically, the government's promotion of acacia and bamboo AFI, directly and indirectly, elevates the opportunity for these farmers to borrow cash for AFI production from different institutions. Appetite and availability of credit for bamboo and acacia alike is reinforced by government focus on resource mobilization, enactment of desirable regulations, and government facilitation for reimbursement or direct involvement when repayments are defaulted or disorders happen.

The majority (46.08%) of the farmers revealed that cooperatives are the chief sources of general farm or agricultural inputs. Around 28% of the farmers procure their farm inputs from the nearest local market centers, whereas 3.1% accessed from district centers (Woreda and Zone). Other farmers also obtained inputs from private sources (12.63%). These private sources comprise their production (self-raised seedlings), relatives, and neighbors. A marginal percentage of farmers (1.02%) specified accessing inputs from the government.

Concerning AFI, 8.53% of the farmers indicated the unimportance of inputs for AFI production. And this is a common practice in bamboo AFI production systems except for a single farmer who used composting. Bamboo producers raise seedlings from their earlier rootstocks or standing trees. Farmers also borrow or freely collect seeds and rootstocks from relatives or neighbors. Ultimately, the establishment costs of bamboo, acacia, and eucalyptus are manageable through family labor and own cash with the current production and management intensity.

#### 4.2.7. Marketing

Often, the farmers acquire market information universally from market surveys (market visits) and neighbors (Table 4). Dealers, cooperatives, and buyers (i.e., during negotiation upon inspection of the AFI plot) serve as sources of market information. Dealers include wholesale traders, brokers, and small scale processors (e.g., bamboo product developers). Inspection is revealed to provide market information since the minimum market value is practically used as the base value by the buyer when presenting his or her offer (i.e., estimated cash value of the AFI or its products).

Table 4. Market information sources for selling AFI products

| | Frequency | Percent |
|---|---|---|
| Market survey | 94 | 36.15 |
| Neighbors | 91 | 35 |
| Dealers | 68 | 26.15 |
| Cooperatives | 4 | 1.54 |
| Gutfeel upon inspection | 3 | 1.15 |

Likert based assessment of farmers' adoption decisions revealed that virtually 78% of the farmers are more motivated by available markets for adopting AFI. Of these, 31.29% are highly motivated by market factors for adopting the respective AFI. Farmers not primarily allured by market opportunities for deciding to adopt AFI accounted for 12.54% of the respondents. The claimants belong to bamboo and eucalyptus AFI production systems. The focus on home consumption needs and the expectation of steady demand are the reasons for the subordinate status of market opportunities for adopting these AFI, particularly eucalyptus. In contrast, all acacia AFI producing farmers claimed market factors primarily drove their AFI adoption. Acacia production is entirely market oriented AFI adoption.

Also, farmers usually sell their AFI mainly as surviving trees on the plot (Figure 3). Cutting, transporting, and selling small quantities of harvest (i.e., retail vending) is abundantly practiced in bamboo AFI. The commonality of retail vending in bamboo AFI is linked to poor market demand where hardly any buyers (whether traders or brokers) visit the locality and procure it wholly (source: hh. no. 23). Contractual based vending of AFI products is also practiced, especially for acacia production.

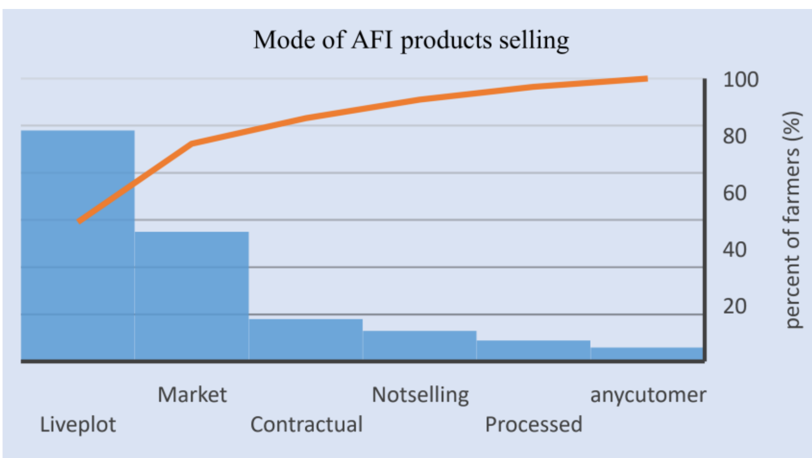


Figure 3. AFI product selling strategy

#### 4.2.8. AFI policies and regulations

Farmers described the absence of impacting AFI policies and regulations in their context. Beyond absence, farmers are honestly unaware of any regulation. Instead, farmers specified some orally informed regulations (Table 5) from extension agents. These regulations are not effected upon defaulters. Just 17.4% of the farmers disclosed an awareness of the presence of AFI related policies or regulations.

Table 5. AFI regulations known by farmers

| Regulations | Explanation | AFI system |
|---|---|---|
| Prohibition on fertile plots | The government intends to use fertile lands to produce cereal, vegetables, and cash crops. So orally, experts inform us that planting on fertile, marshy, and irrigated plots is punishable. Instead, they advise planting on marginal lands and sloppy plots. Purely advisory services are not mandatory and enforced. | Acacia, bamboo, eucalyptus |
| Harvest permission certificate | When the farmers are ready to harvest or sell live trees, experts go to their plots and estimate the amount that can be produced based on the standing density and prior experience. Then, they are provided with a certificate of permission where the harvest can be transported freely. In addition to securing the appropriate tax, this procedure ensures the product comes from private plantations, not from natural forests. | Acacia |
| Spacing from the border | Experts advise that AFI woodlots should be planted farther from the border not to affect the crop production of adjacent plots. Avoid or reduce allelopathic and root (due to lateral root expansion) effects on adjacent contiguous crop production plots. | Eucalyptus, bamboo, and humbly for acacia |
| Complete prohibition | AFI production is not officially permitted. Strong desire from the government, through experts, that it should not be planted at all. Some farmers also aspire to government intervention on alternative means where farmers can reduce AFI production. | Eucalyptus |

A respondent (hh. no. 291) stated that experts informed the farmers that

> *'the law or regulation prohibits plantation of AFI on fertile lands, but no one follows the regulation. Given the long experience, however, farmers plant their AFI especially on fertile plots for early maturity compared to infertile plots'* (source: hh. no.323).

Another respondent (hh. no. 311) pronounced that

> *'in the early days, development agents told us to plant AFI on marginal and rugged plots where crops are not produced. Later, they advised considering the spill-over effects of AFI on crop production. They have abandoned talking about eucalyptus production as they thought the farmers have the full right to plant anything and everything on their private lands despite the government's intention to discourage eucalyptus plantation.'*

Acacia and bamboo productions are highly sensitive to market conditions. Worse market demands instantly devastate production. Farmers might initially uproot their existing production and plant crops instead. Alternatively, farmers could attempt to process the AFI if it is harvested to sell and earn better cash. Consequently, these AFI's future adoption or production in the face of poor market conditions is presumed to be tiny. In contrast, eucalyptus production is expanding in most areas due to intermingling factors, namely, steady market demand, diversity of eucalyptus products, and increasing home consumption demand. Home consumption needs comprising construction, energy, agricultural implement, and fencing continue consolidating the demand for eucalyptus AFI products.

#### 4.2.9. Risks

The questionnaire was prepared to enable farmers to narrate production, marketing, and financial risks. Based on five-year production seasons beginning from the recent (i.e., 2019) and counting backwards, Table 6 describes the issues or risks associated with the respective AFI production. Production risks are mainly related to pests and local climatic variability. Adaptability issues related to soil and agroecology were not production risks listed by farmers. Farmers (hh.no.42 and 43) stated that:

> *'During the summer, frost damages the bamboo culm and rootstock while pests (such as baboons and porcupine) feed on the rootstock and seedlings during winter and occasionally entirely devastate bamboo production.'*

Acacia farmers are enormously anxious about the possible devastation of the AFI plantation due to unimaginable pest and disease incidence. Further, farmers are worried about the negative consequences of acacia production because of the unrestricted, continuing expansion of acacia AFI plantations. Unrestricted expansion or absence of meaningful rule enforcement led to the plantation on fertile plots contradicting oral regulations, such as advising farmers to establish AFI only on marginal and rugged plots. These unrestricted expansions have negative implications on food availability, as narrated by a farmer (hh no. 43)

> *'With all farmers tending or planting their entire or the bulk of their plots with acacia, what will happen to us if diseases destroy the plantation or if there is no more market? Are*

*we and our entire family not going to get starved? We will be starved, and there will be migration to other areas in search of food'.*

Farmers also reflected different contexts, such as

> *'Some farmers from acacia production system* (hh.no. 117 and 118) *even noted good (increased) rainfall conditions afterwards 2016 (up to study year,2019) due to good forested (because of wide acacia plantation) locality. Other farmers* (hh.no. 126 and 130) *observed improved local climatic conditions'.*

Also, *a*cacia producers (hh. no. 156 and 194*)* believe that recent acacia expansion in their locality positively changed the local microclimate, ultimately increasing rainfall and favoring agricultural production*.* In contrast to the above, farmers' perceptions of changing rainfall patterns and local weather variability were unnoticed by other farmers (hh. no. 120)*.* Farmers asserted local climate uniformity in the past 6 years (backwards and including 2019). Overall, around a third (31%) of the respondents distinguish the manifestation of production risks.

Concerning financial risks, farmers (17% of the total 327 respondents) are distressed by the financial issues experienced when settling debit from vendors (hh.no. 39). Merchants frequently settle or repay the farmers after extended and exhaustive negotiations even if the products are sold and transferred to wholesalers or consumers. Farmers sometimes have to force them to repay as some tend to hold and deny it. Besides, farmers worry about a poor financial system associated with credit access, such as cash shortage for wages (hh.no. 6). Also, farmers complain about the unnecessary lengthy bureaucratic process when requesting and issuing harvest certificates.

Marketing risks include excessive supply as almost all local farmers produce it, poor bargaining power related to many brokers, and lack of trust between farmers and vendors due to slow and incomplete cash transfers. Limited innovation, few options of marketable products from these AFI, limited guaranteed or contractual production opportunities, falling demand (i.e., partly due to current political crises in the country inhibiting both transportation of the products and limiting new or broader customer or market base) are the leading market related risks. This political instability and the war in the country is slowing demand for AFI products such as wood and charcoal (even poor pricing for acacia afterward 2018; hh. no. 118). As a consequence of these contexts, the researcher proved that some farmers are uprooting or shifting their AFI plots to traditional crop production.

Table 6. Risk factors and their ranking

| Risk factor | Insights | Opinions among farmers |
|---|---|---|
| Production | Frost, pests, drought, intermittent rainfall conditions, and general local climate variability. Differences among farmers, for example, farmers from acacia production believe recent acacia expansion in their locality positively changed local microclimate, ultimately increasing rainfall amount and favoring agricultural production, whereas others asserted uniformity of local microclimate. | Bamboo is highly susceptible to drought and pests. Climate variability, frost, pests, drought, and intermittent rainfall, are considered devastating risk factors by 66.34%, 23.76%, 4.95%, 2.97%, and 2% of the farmers (from n=101), respectively. |
| Financial | Poor financial institutions lead to acute shortages of cash for wages and investment, high transaction costs and interest rates for accessing credit, and late and even incomplete reimbursement of cash by vendors leading to mistrust between farmers and buyers. | Poor financial systems (87.5%), delayed payment (7.14%), and capital shortage (5.36%) are specified by farmers (n=56) as the key financial risks encountered. |
| Marketing | Poor demand from existing markets and unavailability of new markets, the high number of brokers, remoteness to the main market center, few alternative products, limited and or long market (value) chains, and marginal contractual based production opportunities, decreasing demand compared to previous years. | Poor market demand, the huge number of brokers, decreasing price, remoteness from main market centers, few alternative products, and limited value chains are indicated as marketing risks described by 62.93%, 11.21%, 11.21%, 9.5%, 4.31%, and 0.86% of the farmers (n=116), respectively. |
| Policy | Lack of policy focus, managing like the old days as there is nothing suggested by experts, lack of policy focus led to inaccessible roads during the summer, bureaucracy, or sluggish performance during the provision of harvest certificates. | The presence of poor policies and lack of policy focus, including the undesirability of AFI production, are considered by 69% and 25% of the farmers (n=52). Just 5.77% declared that current policies related to AFI production and marketing are stiff (controlled) and effective. |

n=number of farmers who responded positively to the respective risk factor; hh.no.= household respondent number

Decreasing demand compared to previous years (hh. no.46) and lack of buyers (hh.no. 48 and 49) is reported by farmers. A farmer (hh. no.67) even thought of shifting from bamboo to eucalyptus production due to market unavailability for bamboo and better off market conditions for eucalyptus. Farmers exhibit poor marketing places (i.e, poorly designated) from the three AFI production systems (hh. no.257). Market unavailability due to inaccessible roads to vehicles and lack of labor for carrying (i.e., shoulder transport) the AFI products to the market (hh. no. 88) is underscored as a marketing problem. A farmer (hh.no. 319) stressed the need for infrastructure or accessibility by affirming:

*'unless it is roadside, the AFI plantation will not fetch a good price.'*

Contrary to most farmers, a farmer (hh. no. 213) asserted that the rate of eucalyptus production continues to increase irrespective of local context and quantity supplied. Eventually, vendors' delayed and incomplete cash payment, where farmers are troubled and mistreated, affects further adoption. The complexity and risk related to this delayed payment and even mistreatment is proved by the approach a farmer followed to acquire his cash payments (forced payment) from the vendor:

> *'in one occasion due to very delayed payment and even no response, I threatened the vendor to take his family as hostages unless he pays the cash for my plantation. And of course, worried about his family, he paid the cash.' (hh. no. 293).*

For policy risks, the poor policy contexts are displayed through lengthy harvest certificate granting procedures, discouragement of eucalyptus AFI plantation, poor infrastructure conditions as the government doesn't invest in the source of marketing products, and marginal implementation of regulations related to prohibition of AFI on fertile lands. The continuation of traditional management methods and the absence of new expert suggestions or technical recommendations from experts (hh.no. 49) is pronounced by farmers as a poor policy context for better AFI productivity and production. Other farmers expressed a bunch of issues, such as:

> *'Due to lack of focus on bamboo production, the road is inaccessible during summer* (hh.no.89). *We have to wait a week to get a piece of paper* (permission certificate for acacia production, hh.no.155). *Some development agents refuse to grant inputs to farmers who planted eucalyptus* (hh. no. 209). *The government ordered not to raise eucalyptus seedlings and 3 years back, imprisoned (and even warned to take their plot) those who raised and bought eucalyptus seedlings for plantation* (hh.no.213). *Further expansion and product movement are getting worse as the government's regulation of no eucalyptus plantation is effected'* (hh.no.257,258, 260).

Generally, current national contexts have resulted in contradictory outcomes on AFI adoption. Farmers continue to engage in AFI production due to costly inputs for traditional farming.

Contrastingly, the government promotes AFI production first on marginal plots and inhibits it on fertile plots. Second, the government entirely prohibits further adoption of eucalyptus AFI. Nevertheless, farmers continue to establish AFI on fertile plots and adopt eucalyptus AFI. Lack of alternative market opportunities and poor enforcement of AFI related regulations have thus resulted in mixed AFI adoption from the standpoint of government intentions. To fulfill the livelihood needs of farmers, the government's two opposing AFI related intentions (i.e., promotion of degraded plots and getting rid of fertile and irrigated plots) require close monitoring and implementation.

Another justification for AFI adoption's poor or contradictory performance is linked to poor innovations (i.e., developing various products) for all products, as value addition is still at its basic stage. The use of local AFI for high end furniture products is yet to get momentum. Acacia is formally needed for fuel (mainly charcoal or fuel wood), and bamboo is regularly used for local furniture products. Bamboo products have significantly fluctuating demand, and the continuing poor product development aspects past the ordinary products such as local furniture consolidate largely declining demand and pricing. Despite the multipurpose nature of eucalyptus AFI, its adoption is expanding in some areas while declining in other localities. The decline of eucalyptus AFI adoption is linked to spillover effects on traditional crop production, growing demand for vegetables under irrigated agriculture, and recent attractive prices for some crops such as Teff. The increasing adoption of AFI is associated with costly inputs for traditional crop production and the enduring demand for all eucalyptus AFI products.

### 4.3.Influence of system level features on AF adoption

Production risk initially, live plot mode of marketing (i.e., selling the surviving tree while on the plot), financial risk, credit, and distance to the main road significantly affected the adoption of AFI woodlots in the second and third rounds of adoption decision (Table 7). As expected, farmers are initially worried about production risks related to climate variability, pests and diseases, and drought. The existence of associated production risks decreases the adoption extent by 0.65 units. Explicitly stated, if a farmer believes that the AFI woodlots are sensitive to one of the production risk factors, the adoption extent initially or in the first year declines by 0.16ha.

Table 7. Determinants of system level features on successive AFI adoption

| | Coefficient | Std. Error | P |
|---|---|---|---|
| Year 1 | | | |
| Government as package source | 0.117334 | 0.2553775 | 0.646 |
| Training | -0.740942 | 0.6011796 | 0.218 |
| Distance to Woreda | -0.0016487 | 0.0020452 | 0.420 |
| Distance to Kebele | 0.0001333 | 0.0021591 | 0.951 |
| Production risk | -0.6495796 | 0.2284889 | 0.004 |
| Constant | 1.437977 | 0.3586792 | 0.000 |
| Year 2 | | | |
| Distance to main road | 0.0002817 | 0.0015294 | 0.854 |
| Distance to nearest market | 0.0014126 | 0.0016273 | 0.385 |
| Extension | 0.222685 | 0.2833159 | 0.432 |
| Credit | -0.5993261 | 0.2792912 | 0.032 |
| Production risk | -0.0581074 | 0.2769122 | 0.834 |
| Financial risk | -0.7154008 | 0.4459084 | 0.109 |
| Live plot mode of selling | 1.078856 | 0.3271495 | 0.001 |
| Market oriented production | -0.1378988 | 0.2768862 | 0.618 |
| Policy risk intensity | 0.0443841 | 0.082371 | 0.590 |
| Constant | 0.8100726 | 0.3965706 | 0.041 |
| Year 3 | | | |
| Distance to main road | 0.004266 | 0.0020071 | 0.034 |
| Distance to nearest market | 0.0015178 | 0.0021337 | 0.477 |
| Extension | -0.1672615 | 0.3729676 | 0.654 |
| Credit | -0.3528201 | 0.3678984 | 0.338 |
| Production risk | -0.0583 | 0.3629083 | 0.872 |
| Financial risk | -1.37055 | 0.5874157 | 0.020 |
| Live plot mode of selling | 1.266312 | 0.4311902 | 0.003 |
| Market oriented production | -0.3836035 | 0.3645247 | 0.293 |
| Policy risk intensity | 0.0516768 | 0.1085144 | 0.634 |
| Constant | 0.7210123 | 0.521177 | 0.167 |

Seemingly unrelated regression; dependent variables, adoption for first, second and third years (rounds) measured in Timad/Kada (0.25ha); No observations=28; R-sq is 0.256,0.4357 and 0.4377 for year 1, year2 and year 3 adoption decisions. All distances are measured in minutes traveled.

Similarly, second year adoption is influenced negatively by two system level features: financial risk and credit. A farmer who accessed credit is less likely to make second round adoption compared to a farmer who never accessed credit. Access to credit decreases the extent of second year adoption by 0.15ha. The inverse relationship of credit to second round adoption extent is related to the use of credit for intensifying traditional crop production. Table 4 also proves that farmers primarily use credit to purchase draft power, the common tool for farm operations such as land tilling.

Regarding financial risk, if a farmer perceives that the AFI woodlot is sensitive to any of the financial risks (i.e., poor financial access, delayed cash payment, and capital shortage), then the adoption extent for the second round is reduced by 0.18ha. In contrast, if a farmer dominantly follows the live plot mode of selling the AFI product, selling the live plantation while still on the plot, then he or she likely adopts a comparably greater magnitude of AFI woodlots. When the principal vending mode of farmers is live on plot, the magnitude of AFI woodlot adopted surges by 0.27ha.

Third round adoption is facilitated by distance to the main road and live plot mode of selling, whereas negative with perceived financial risk. The magnitude of AFI adopted increases as the farmers reside farther away from the main road. A minute more distance a farmer resides from the main road, the magnitude of third round adoption increases by 0.0010665ha. Despite the marginal magnitude of change, the relationship indicates that farmers preferably attempt or are inclined to engage in AFI production when they are farther from the main road. This is linked to poor road access inhibiting market-oriented products' production. Likewise, when a farmer perceives financial risks associated with AFI production, the adoption extent in the third round decreases by 0.34ha.

A prior negative experience in cash shortage and mainly cash reimbursement issues (Table 6) after the vendors take at first with credit leads farmers to have poor trust and subsequently moderate their adoption extent in the successive periods. Eventually, the extent of AFI adoption surges by 0.32ha when farmers access the largely preferred mode of selling (i.e., live on the plot). Few farmers also prefer retail vending, either raw or processed. Generally, most farmers prefer wholesaling while the tree is surviving on the plot to evade concerns related to harvesting, processing, transporting, and marketing. Despite appealing marketing mode, adoption extent declines in the latter stages due to limited land availability and market saturation. We also noticed an increasing influence of financial risk from second to third round adoption decisions. Finally, we detected increasing variance explanation power of the models from first to second and slightly to third round from their $R^2$. We interpreted this observation as the relevance of system level features particularly related to marketing, and financial risks, are more important in the advanced stages of adoption decisions.

Based on Zeller (1962), the SUREG model revealed the presence of contemporaneous correlation among error terms on parameter estimates. The estimated Breusch-Pagan test of independence ($x^2(3)$ =23.875) is significant at less than one percent level (p = 0.0000). Accordingly, the residuals of the adoption decision functions are contemporaneously correlated. The residuals are dependent, indicating that SUREG variables are more efficient than OLS (ordinary least squares). Further, correlation tests during model development showed correlation among dependent variables (i.e., adoption at first, second, and third rounds). Magnitudes of the second (0.3645) and third (0.3407) round adoptions are correlated moderately to the extent of initial season adoption. Moreover, the adoption magnitude of third round is strongly correlated (0.777) to the adoption magnitude of second round adoption. Overall, the models showed adequate $R^2$ values (i.e., 26% for the first and 46% for each second and third round) and supported the good fit of the estimated models (Acharya et al. 2018). The models' relatively moderate variance explanation power (i.e., R2) is accredited to the explicit employment of system level features, which disregarded household contexts and innovation characteristics variables, for predicting the factors affecting AFI adoption.

## 5. Discussion

With more than a decade of average experience, the farmers in our study area are experienced well in both traditional and 'newly' introduced AFI production. Based on experience, marginally few farmers practice intercropping in bamboo AFI to avoid uprooting the bamboo rootstock during harvesting of the intercrop. Consequently, farmers practice sole bamboo production, whereas acacia and eucalyptus producers largely practice intercropping during the initial plantation year. Such intercropping of the AFI reduces (thwarts) risks associated with adopting the AFI, builds farmers' confidence, and increases the benefits from that particular plot (i.e., from crops, by-products such as straw, and ultimately from the AFI). Traditionally grass or animal feed is harvested in the second year after the complete flourishing (i.e., the clear generation) of seedlings. Often also farmers allow livestock to graze as a form of feed access for the livestock and a weeding strategy. Nigussie et al. (2020) indicated that intercropping of acacia with cereals such as Teff helps to offset income loss, improve soil fertility and restore degraded plots.

In ascending order, the farmers travel relatively long distances to reach Kebele offices, the nearest market centers, the main road, and Woreda offices. The provision of vital public services (particularly the congregation at Kebele) around the vicinity of farmers' residences is consistent with the earlier government's efforts of a public extension delivery mechanism that extends from the federal ministry to the Kebele (Bachewe et al. 2018). The unprecedented expansion of the agricultural extension system led to better performance of smallholder agricultural production

(Berhanu and Poulton 2014). The proximity of service centers is positively associated with better productivity (Abate et al., 2020). While the exact difference between the proximity of the farmers to the administration centers varies, it roughly lies within the government's proposal of building central administration and public delivery centers nearby the farmers' residences (OECD 2020; Assefa et al. 2019). In the Sahel (i.e., Senegal and Niger), distance to the market center increased investment intensity on farmland AF (Binam et al. 2017). In Ethiopia, proximity to cities strongly affects agricultural product prices (Vandercasteelen et al., 2018).

The public advisory service is largely focused on enhancing traditional crop production, including adopting new varieties and improving management practices, marketing agricultural commodities, and natural resource management. Advisory services' focus matches former government efforts to increase crop productivity and improve food security by delivering comprehensive extension services (Abate et al. 2019; Abate et al. 2020). Few farmers participated in field days aimed at the production of general agriculture, demonstration of new AFI, and observed the benefits from early adopters. On-farm demonstration, one of the extension systems, can effectively achieve desired objectives when adequately designed (Alexopoulos et al. 2021). A comprehensive FAO led assessment of extension advisory services in developing countries provided an insight that lack of adequate policies addressing agricultural extension, insufficient funding, and poor infrastructure are the bottlenecks for the effectiveness of these extension advisory services (Blockeel et al. 2022).

Credit for AFI production is marginally accessed. Shortage of credit specifically for AFI production and the bureaucratic contexts for credit access, the availability of sufficient capital for AFI production, and the unnecessary credit for AFI production remain the possible justifications for nominal access and expenditure of credit for AFI production. In the context of traditional AFI, Amare et al. (2019) found a positive association between credit access to the intensity of farmland AFI adoption.

Regulations related to AFI production are concerted on promoting AFI production on marginal lands, prohibition on fertile lands, and spacing from adjacent borders. Even if it was promoted in the early days, Eucalyptus AFI is currently openly prohibited. Nevertheless, farmers' interest due to push (i.e., progressively costly inputs for traditional crop production) and pull factors (i.e., market demand and home consumption needs) has driven the adoption of eucalyptus AFI.

Concerns related to AFI comprise production, financial, marketing, policy, and regulations factors. AFI regulations are unfamiliar, poorly designed, and effected in the study areas. Binam et al. (2017) and Amare et al.(2019) found mixed effects of local institutions on farmer managed forest restorations in the Sahel region and farmland forests, respectively. Communities with well-structured formal and informal institutions showed better collaboration attitudes and adherence to local institutional regulations (Binam et al. 2017).

Econometric models revealed that production risks related to resistance to pests, drought, and fluctuating rainfall contexts (i.e., high rainfall is not alleged as a problem but rather reputed as a suitable condition for AFI production) influence AFI adoption. Investment capital in the form of credit, distance to the main highway (i.e., as a proxy for market availability as vendors can easily observe, negotiate and buy the AFI), and financial risks are important for further adoption of AFI.

## 6. Conclusion

System level features are key factors for making AFI adoption decisions, especially in market-oriented innovations like these AFI. We embrace and promote systems adoption studies, as the coefficient of determination-R2 verified that system level features explained only 26%-44% of the AFI adoption decision of the farmers, and the rest of the variance for making AFI adoption for this particular farmers is explained by other variables including psychological factors (Amare and Darr 2022). Future studies should fairly examine the role of system level features in greater depth by employing thematic and quantitative analysis methods. Such exploration consolidates the desire to broaden the research base to have more insightful information about the factors affecting the adoption of AFI, in addition to focusing on the frequently explored socioeconomic variables (Glover et al. 2019; Glover et al. 2016). Such exploration ultimately will impact policy and action by driving policy designs and development actions based on research findings instead of government and individual intentions (Amare and Darr 2020). Prospective studies in understanding contexts affecting smallholder farmers AFI or the adoption of more considerable agricultural innovations should incorporate this, system level features, and perspectives for a more profound and insightful understanding.

Supplementary file: Appendix E

## Publication bibliography

Abate, Gashaw T.; Bernard, Tanguy; Makhija, Simrin; Spielman, David J. (2019): Accelerating technical change through video-mediated agricultural extension: Evidence from Ethiopia: Intl Food Policy Res Inst.

Abate, Gashaw T.; Dereje, Mekdim; Hirvonen, Kalle; Minten, Bart (2020): Geography of public service delivery in rural Ethiopia. In *World development* 136, p. 105133. DOI: 10.1016/j.worlddev.2020.105133.

Abiyu, Abrham; Teketay, Demel; Gratzer, Georg; Shete, Maru (2016): Tree Planting by Smallholder Farmers in the Upper Catchment of Lake Tana Watershed, Northwest Ethiopia. In *Small-scale Forestry* 15 (2), pp. 199–212. DOI: 10.1007/s11842-015-9317-7.

Acharya, Ram (2018): The Effects of Changing Climate and Market Conditions on Crop Yield and Acreage Allocation in Nepal. In *Climate* 6 (2), p. 32. DOI: 10.3390/cli6020032.

Alexopoulos, Y.; Pappa, E.; Perifanos, I.; Marchand, F.; Cooreman, H.; Debruyne, L. et al. (2021): Unraveling relevant factors for effective on farm demonstration: the crucial role of relevance for participants and structural set up. In *The Journal of Agricultural Education and Extension* 27 (5), pp. 657–676. DOI: 10.1080/1389224X.2021.1953550.

Amare, Dagninet; Darr, Dietrich (forthcominga): Adoption under the influence of innovation attributes: The case of agroforestry innovations from Ethiopia.

Amare, Dagninet; Darr, Dietrich (forthcomingb): Can a sequential analysis provide a more robust understanding of farmers' adoption decisions? An example from an agroforestry adoption study in Ethiopia. In *Ecological Economics*.

Amare, Dagninet; Darr, Dietrich (2020): Agroforestry adoption as a systems concept: A review. In *Forest Policy and Economics* 120, p. 102299. DOI: 10.1016/j.forpol.2020.102299.

Amare, Dagninet; Darr, Dietrich (2022): Farmers' intentions towards sustained agroforestry adoption: An application of the theory of planned behavior. In *Sustainable Forestry*.

Amare, Dagninet; Mekuria, Wolde; Belay, Beyene (2017): Willingness and Participation of Local Communities to Manage Communal Grazing Lands in the Lake Tana Biosphere, Ethiopia. In *Society & Natural Resources* 30 (6), pp. 674–689. DOI: 10.1080/08941920.2016.1264649.

Amare, Dagninet; Mekuria, Wolde; T/wold, Tilaye; Belay, Beyene; Teshome, Akalu; Yitaferu, Birru et al. (2016): Perception of local community and the willingness to pay to restore church forests: the case of Dera district, northwestern Ethiopia. In *Forests, Trees and Livelihoods* 25 (3), pp. 173–186. DOI: 10.1080/14728028.2015.1133330.

Amare, Dagninet; Wondie, Menale; Mekuria, Wolde; Darr, Dietrich (2019): Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. In *Small-scale Forestry* 18 (1), pp. 39–56. DOI: 10.1007/s11842-018-9405-6.

Assefa, Yibeltal; Gelaw, Yalemzewod Assefa; Hill, Peter S.; Taye, Belaynew Wassie; van Damme, Wim (2019): Community health extension program of Ethiopia, 2003-2018: successes and challenges toward universal coverage for primary healthcare services. In *Globalization and health* 15 (1), p. 24. DOI: 10.1186/s12992-019-0470-1.

Bachewe, Fantu N.; Berhane, Guush; Minten, Bart; Taffesse, Alemayehu S. (2018): Agricultural Transformation in Africa? Assessing the Evidence in Ethiopia. In *World development* 105, pp. 286–298. DOI: 10.1016/j.worlddev.2017.05.041.

Balmann, Alfons; Valentinov, Vladislav (Eds.) (2016): Towards a Theory of Structural Change in Agriculture: Just Economics? 149th EAAE on Structural change in agri-food chains: new relations between farm sector, food industry and retail sector. Rennes, France, October 27-28.

Bantihun Mehari, Abay; Abera, Melese Worku (2019): Opportunities and challenges of adopting home garden agroforestry practices in Ethiopia: A review. In *Cogent Food & Agriculture* 5 (1), p. 1618522. DOI: 10.1080/23311932.2019.1618522.

Basinger, M.; Chen, J.; Jeffrey-Coker, F.; Rodriguez-Sanchez, F. S.; Singer, T.; Modi, V. (2012): Jatropha adoption: a statistical observational study of factors influencing Malian farmers’ decision to grow Jatropha. In *Agroforest Syst* 84 (1), pp. 59–72. DOI: 10.1007/s10457-011-9426-z.

Berhanu, Kassahun; Poulton, Colin (2014): The Political Economy of Agricultural Extension Policy in Ethiopia: Economic Growth and Political Control. In *Development Policy Review* 32 (s2), s197-s213. DOI: 10.1111/dpr.12082.

Binam, Joachim N.; Place, Frank; Djalal, Arinloye A.; Kalinganire, Antoine (2017): Effects of local institutions on the adoption of agroforestry innovations: evidence of farmer managed natural regeneration and its implications for rural livelihoods in the Sahel. In *Agric Econ* 5 (1). DOI: 10.1186/s40100-017-0072-2.

Blockeel, Johan; Chuluunbaatar, Delgermaa; Holley, Aiden; Sulaiman, Rasheed; Djamen, Patrice; Grovermann, Christian (2022): Taking a snapshot of Extension and Advisory Systems performance and outcomes: insights on a semi-quantitative evaluation approach. In *The Journal of Agricultural Education and Extension*, pp. 1–21. DOI: 10.1080/1389224X.2022.2089178.

Douthwaite, Boru; Hoffecker, Elizabeth (2017): Towards a complexity-aware theory of change for participatory research programs working within agricultural innovation systems. In *Agricultural Systems* 155, pp. 88–102. DOI: 10.1016/j.agsy.2017.04.002.

Feder, Gershon; Just, Richard E.; Zilberman, David (1985): Adoption of Agricultural Innovations in Developing Countries: A Survey. In *Economic Development and Cultural Change* 33 (2), pp. 255–298. DOI: 10.1086/451461.

Glover, Dominic; Sumberg, James; Andersson, Jens A. (2016): The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. In *Outlook Agric* 45 (1), pp. 3–6. DOI: 10.5367/oa.2016.0235.

Glover, Dominic; Sumberg, James; Ton, Giel; Andersson, Jens; Badstue, Lone (2019): Rethinking technological change in smallholder agriculture. In *Outlook Agric* 48 (3), pp. 169–180. DOI: 10.1177/0030727019864978.

Hekkert, M. P.; Suurs, R.A.A.; Negro, S. O.; Kuhlmann, S.; Smits, R.E.H.M. (2007): Functions of innovation systems: A new approach for analysing technological change. In *Technological Forecasting and Social Change* 74 (4), pp. 413–432. DOI: 10.1016/j.techfore.2006.03.002.

Issa, Fadlullah Olayiwola; Kagbu, Joyce Hauwa (2017): Institutional Factors Influencing Crop Farmers Adoption of Recommended Agrochemical Practices in Nigeria. In *Journal of Agricultural Extension* 21 (1).

Kim, Jaeoh; Cho, HyungJun (2019): Seemingly unrelated regression tree. In *Journal of Applied Statistics* 46 (7), pp. 1177–1195. DOI: 10.1080/02664763.2018.1538327.

McDowell, Allen (2004): From the help desk: Seemingly unrelated regression with unbalanced equations. In *The Stata Journal* 4 (4), pp. 442–448.

Mendelson, Sophia; Gold, Michael; Lovell, Sarah; Hendrickson, Mary (2021): The agroforestry academy: assessing long-term outcomes and impacts of a model training program. In *Agroforest Syst* 95 (4), pp. 601–614. DOI: 10.1007/s10457-021-00604-y.

Mercer, D. E. (2004): Adoption of agroforestry innovations in the tropics: A review. In *Agroforest Syst* 61-62 (1-3), pp. 311–328. DOI: 10.1023/B:AGFO.0000029007.85754.70.

Montambault, Jensen Reitz; Alavalapati, Janaki R. R. (2005): Socioeconomic research in agroforestry: a decade in review. In *Agroforest Syst* 65 (2), pp. 151–161. DOI: 10.1007/s10457-005-0124-6.

Nabaasa, Edgar; Kalibwani, Rebecca M.; Ssemakula, Edward; Mujuni, Boaz (2022): Institutional Factors and Technology Adoption amongst Smallholder Coffee Farmers in Kanungu District South-Western Uganda.

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Tsubo, Mitsuru; Ayalew, Zemen; Abele, Steffen (2020): Economic and financial sustainability of an Acacia decurrens-based Taungya system for farmers in the Upper Blue Nile Basin, Ethiopia. In *Land Use Policy* 90, p. 104331. DOI: 10.1016/j.landusepol.2019.104331.

OECD (2020): Rural Development Strategy Review of Ethiopia: OECD.

Rogers, E. M. (1983): Diffusion of Innovations. 3rd. New York: The Free Press.

Rogers, E. M. (2003): Diffusion of Innovations. 5th. New York: The Free Press.

Straub, Evan T. (2009): Understanding Technology Adoption: Theory and Future Directions for Informal Learning. In *Review of Educational Research* 79 (2), pp. 625–649. DOI: 10.3102/0034654308325896.

Vandercasteelen, Joachim; Beyene, Seneshaw Temru; Minten, Bart; Swinnen, Johan (2018): Big cities, small towns, and poor farmers: Evidence from Ethiopia. In *World development* 106, pp. 393–406. DOI: 10.1016/j.worlddev.2018.03.006.

Windsor, Fredric M.; Armenteras, Dolors; Assis, Ana Paula A.; Astegiano, Julia; Santana, Pamela C.; Cagnolo, Luciano et al. (2022): Network science: Applications for sustainable agroecosystems and food security. In *Perspectives in Ecology and Conservation* 20 (2), pp. 79–90. DOI: 10.1016/j.pecon.2022.03.001.

Wordofa, Muluken G.; Hassen, Jemal Y.; Endris, Getachew S.; Aweke, Chanyalew S.; Moges, Dereje K.; Rorisa, Debbebe T. (2021): Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. In *Agric & Food Secur* 10 (1). DOI: 10.1186/s40066-020-00278-2.

Zellner, Arnold (1962): An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests forAggregation Bias. In *Journal of the American Statistical Association* 57 (298), pp. 348–368. Available online at http://www.jstor.org/stable/2281644.

Zerihun, Mulatu Fekadu (2020): Institutional Analysis of Adoption of Agroforestry Practices in the Eastern Cape Province of South Africa. In *SAJEE* 36. DOI: 10.4314/sajee.v36i1.9.

# 5. SYNTHESIS and CONCLUSION

## 5.1. Synthesis of key findings

### 5.1.1. State of AFI adoption research in SSA

Since embracing AF/AFI as a modern and improved land use system suitable for scientific study in the 1970s, adoption research has been conducted in AFI (Mercer and Miller 1998). Biophysical perspectives dominated the early years of AFI adoption research in the 1970s and 1980s. The transformation of improved agroforestry systems from research institutions to rural development projects created the question of the inadequacy of socioeconomic research. The desire for satisfying socioeconomic research grew as AF became an established focus of international rural development efforts (Mercer and Miller 1998). Despite conducting individual research on project interventions, synthesis of the general outlook of AFI adoption research was lacking.

To improve the information summarization and provide feedback for prospective adoption research, researchers started appraising the progress of socioeconomic research in AF. Mercer and Miller (1998) are the earliest researchers who evaluated the progress of AFI adoption research. Based on publication in the 'Agroforestry journal', the predominant journal outlet for AF adoption research at the time, Mercer and Miller (1998) evaluated the under-researched socioeconomic subjects in AF. Socioeconomic research in AF was conducted by only 22% of the papers published in the journal during 1982-1996. Researchers later reviewed AF adoption research with the objectives of understanding the general determinants of AFI adoption in the tropics (Pattanyak et al. 2003), knowing why and how tropical farmers adopt AFI (Mercer 2004), comprehending the trend of global economic and social research in AFI (Moutambault and Alavalapati 2005), identification of the intrinsic and extrinsic factors affecting SSA farmers AFI uptake (Meijer et al. 2015) and bamboo suitability and benefits analysis in SSA (Partey et al. 2017). These literature assessments following thematic and meta-analysis (Grant and Booth, 2009) appreciated the progress towards an increased number of AF socioeconomic research and the use of economic methods for better generalization and inferential statistics.

Following the recent gap in synthesizing the AFI adoption research, we conducted a review of AFI adoption research in SSA for the period 2005-2019 (Amare and Darr 2020, Chapter 4.1). The desire to appraise AFI adoption research in SSA is due to the huge potential AFI have on the livelihood improvement of smallholder farmers, which represents a larger proportion of the total population in the region, and the prospective for reducing risks related to climate change and poor prices of agricultural commodities (FAO 2020). With the application of the systematic review technique (chapter 4.1), we selected 82 individual studies. We evaluated the focus of their research, study location, subject area coverage and data collection and analysis methods, and further suggestions. Our review found that most of the AFI adoption studies in SSA are conducted in East and slightly West Africa. The Southern Africa region is underrepresented in AFI adoption research in these periods.

Despite few studies employing a mix of methods, looking into the data collection landscape revealed that 98% of the documents used the household survey as the primary data collection method. A peculiar method employed is document analysis for AF regulations or policies assessment. Econometric modeling and descriptive statistics are the predominant analytical tools (Chapter 4.1., Table 2). Despite improvements, econometric models frequently employed dichotomized (i.e., adopt/non-adopt) dependent variables from cross-sectional data.

Econometric and descriptive research studies explored a diversity of variables. These AFI adoption studies in SSA explore institutional, behavioral, livelihood, social capital, infrastructure, constraints, and market factors (Figures 2 and 3, chapter 4.1). Demographic related factors are the most sought after and investigated variables. Despite a comparably better execution to significance ratio, investigations on innovation attributes' contribution to AFI adoption are scarce (page 6, Amare and Darr 2020). The relationship between the executed variables and AFI adoption is inconsistent, instead significantly correlated (i.e., either positively or negatively) or unassociated with the AFI adoption decision. Yet, the progress of AFI adoption research in SSA in the specified period is marginal. The marginality of the progress is due to the absence of disruptive research, barely new variables and approaches, leading to better insights. We hardly noticed any major changes in development direction and policy regulation, mainly due to the input of research recommendations. Therefore, we embrace previous critiques of adoption research's negligible impact on SSA development (Glover et al. 2016).

### 5.1.2. Persistent calls for rigorous research

The review papers and individual studies discovered long lists of factors that facilitate or hinder AFI adoption (Kiptot et al. 2006; Amare and Darr 2020). Yet adoption research partly failed to produce meaningful results that affect prospective adoption intervention. Policy and action marginally incorporated the suggestions of these studies for improving the implementation of ongoing or new development programs. Policy and development actions continued due to government intent, not based on scientific evidence. The poor application of diverse methods and approaches, inconsequential description, and contextualized interpretation of results applicable to similar contexts or globally was lacking. As a result, researchers in the AFI sector, from Mercer and Miller (1998) to Amare and Darr (2020), persistently requested rigorous research that directly affects policy and development directions. Indeed, researchers addressed some of the previous suggestions. Subsequent AFI adoption studies partially addressed the earliest suggestion of Mercer and Miller (1998) by employing largely adequate sample sizes and applying economic models and inferential analytical methods.

Nevertheless, gaps in AFI adoption research persist. For example, studies insufficiently explored policy, risk, and uncertainty (Mercer and Miller, 1998). The prevalence of bias towards establishing significance (Pattanyak et al. 2003) is still a prominent issue as researchers primarily dwell on re-inventing the wheel by focusing on a smaller group of variables while studying AFI adoption (Amare and Darr 2020). Incorrect treatment of variables in econometric models (Mercer 2004) and the poor incorporation of intrinsic factors (Meijer et al. 2015) are issues not sufficiently addressed, as proved from the list of variables addressed by AFI socioeconomic research in SSA (chapter 4.1).

Beyond individual studies and reviews, researchers have called for improved concepts on embracing the fluid assembly of components an innovation (i.e., an innovation can be modified to fit farmers capacities and needs), not the usually static perspective as an object inflexible for modifications (Glover et al 2016), evading the over-simplification of adoption (Rogers 2003) and presumption of adoption as a complex decision process (Hoffman 2007), observation and application of the temporal variation of AFI adoption decision, exploration of the larger adoption context instead of the frequently visualized limited and fragmented perspectives (chapter 4.1., Amare and Darr 2020), the visualization of adoption beyond adopt-non-adopt dichotomy to a more continuous variable and the adaptation of theoretical and analytical frameworks that encompass the diverse perspectives that affect smallholders AFI adoption decisions were persistently stated and largely encouraged and welcomed by previous reviews; in addition to the fragmented and specific suggestions forwarded by the discrete studies. The broader incorporation of psychological aspects, the application of robust analytical tools, the incorporation of many distinguishing features (innovation characteristics), and systems thinking or holistic approach are still lacking in socioeconomic AFI adoption research.

### 5.1.3. Critical factors affecting AFI adoption

Based on the feedback and inputs from previous research, fieldwork was conducted between 2019 and 2021 to investigate the factors affecting the adoption of AFI in the Amhara region of Ethiopia, representative of the larger SSA smallholder population. First and foremost, we examined the perspectives affecting AFI adoption and responded to the proposed research objectives (chapter 1, 1.3). Below we discuss the perspectives and responses to the research questions.

Due to this dissertation's iterative learning and practice approach, we employed Amare and Darr's (2020) AFI adoption analytical framework. Consequently, household contexts (chapters 4.2 and 4.3), innovation attributes (chapter 4.4), and system level features (chapter 4.5) are explored in connection with their impact on AFI adoption. Regarding household contexts, we found that farm level factors influence AFI adoption, and their influence ranges from 50-70%, as expressed in variance explanation power (chapter 4.2). A relative increase in farm size increases the adoption intensity for the three adoption rounds consistently. In contrast, an increase in family size consistently decreases the AFI adoption intensity in all three rounds. Relatively higher livestock and asset index decreases and increases magnitudes of initial and second round AFI adoption, respectively. Farm activity income increases AFI adoption's magnitude during the second and third rounds. A family principally adhering to the absolute power index has a decreased magnitude of AFI adoption during initial and second round adoptions. Variables related to assets (wealth such as farm size and family size), earnings from other sources, and decision making patterns most likely affected the AFI adoption decision. Despite a consistent direction of the relationship of these variables with AFI adoption, the intensity of significance and magnitude of the relationship varied across adoption periods. We further demonstrated the superiority of retrospective analysis (Gibson and Kim 2005) compared with cross-sectional analysis and proved the flaw of the static and dichotomized, adopt-non-adopt research approach. By undertaking this analysis, we responded to research question 2: What specific farm level, both the family and the resources, factors influence the decision to adopt, increase or abandon? In the process, we proved that farm level factors are essential components that affect the AFI adoption decisions of farmers. By employing a retrospective data inquiry and process analysis, we found that farmers make follow-up AFI adoptions beyond the first time (or initial) pilot adoption. These follow-up adoptions proceed with reduced, maintained, or increased patterns (Chapter 4.2.).

Further inquiry proved the importance of intrinsic or psychological variables, an element of the household contexts variables category. Due to the call for a focus on intrinsic factors (Meijer et al. 2015) and the famous TPB (Ajzen 2010), we explored the influence of psychological factors on the AFI adoption decision of our farmers. Results from the inquiry proved that attitude, subjective norms, and perceived behavioral control are integral to farmers' AFI adoption decisions and are positively and significantly associated with AFI adoption (Amare and Darr 2022). By undertaking this study, we responded to research question 3, which states that psychological factors matter in making AFI adoption decisions. Previous studies (e.g., Meijer et al. 2015) called for a focus on intrinsic (i.e., psychological) factors. Psychological constructs such as attitudes, perceived behavioral control, and subjective norms are essential variables influencing decisions on whether or not to adopt AFI. By doing this discrete analysis, we consolidated previous studies call that researchers should explore the importance of psychological or behavioral variables for making adoption decisions under smallholder contexts.

Based on the ‘AFI adoption framework,’ we explored the importance of innovation characteristics in adopting AFI. In the under researched area, innovation characteristics confirmed that intrinsic attributes of the AFI influence farmers’ adoption decisions (chapter 4.4). As Rogers (2003) stated and explored in many manufactured good contexts, innovation characteristics are essential for farmers to proceed with adoption decisions. In chapter 4 (sub-chapter 4.4.), we developed additional attributes beyond the original five attributes and found that these attributes are critical for making AFI adoption. The sequential analysis proved that biological features (such as adaptability), production tasks, social and economic benefits, and compatibility features are essential for smallholders to make favorable adoption decisions on newly introduced or prior known AFI. Beyond Roger's (2003) original five attributes, we proved there is a possibility of including and excluding various attributes linked to adopting a specific AFI. With a temporal variance explanation of 16-60%, innovation attributes play a central role in the adoption decision of AFI woodlots. However, we observed that innovation attributes are not always crucial for decision making, as proved by the non-significance of the model during the second adoption.

Last, with a variance explanation power between 26% and 44%, system level features are critical factors for making adoption decisions (chapter 4.5). The variance explained by system level features during second and third round adoptions is slightly lower than twice that of AFI adoption during the first adoption round. The importance and requirement for intensive support systems, especially in the context of market-oriented production systems, are more vital in the follow-up adoption decisions. Production risks, distance to the main road, marketing strategy, particularly live plot marketing, and financial risks are the main system level features that influence AFI adoption (Table 7, chapter 4.5). Mode of selling is also an important parameter that positively influences the adoption of AFI. Extension advisory service, however, does not contribute to or influence the fate of adoption decisions. Despite playing a likely substantial and beneficial role in the majority of assessed studies, advisory services with the deployment of AFI are likely insignificant. Except for the license certification, these services are not necessary for this already established production system (chapter 4.1). Current advisory services do not focus on AFI production, as proved by marginal input and training services and open discouragement for eucalyptus production. Despite good infrastructure availability for essential services, generally poor infrastructure accessibility, particularly regarding road access, discourages bamboo AFI adoption. Examination of system level factors separately proved that (i) these factors are essential for AFI adoption decisions, and (ii) other sets of variables (namely household contexts and innovation attributes) contribute to the remaining variance for making the adoption. Beyond responding to the research question, what system level factors affect AFI adoption? We displayed that system level features importance varies across adoption rounds. The support and services from various stakeholders or actors are needed at various AFI adoption stages, and the intensity of support required also differs accordingly, affecting ultimate AFI adoption.

### 5.1.4. Conceptualizing adoption as a complex decision process

Beyond past static views and the famous Rogers's five stages assumptions and practices, we strived to understand an AFI as a fluid assembly of components that can be modified. We are driven explicitly by the more elaborate commentaries of Glover et al. (2016), who made a great leap toward unlocking and comprehending the adoption problem in SSA. For example, in the analysis, we learned that farmers make further adoption decisions past their initial adoption. These adoption decisions are either the same size (measured in ha units) or an equivalent amount to the previous adoption extent or a reduced size compared to their initial or previous adoption magnitude. Farmers also made abandonment decisions past their initial adoption. Most studies followed adopt/non-adopt dichotomy concept despite Rogers depicting adoption as following five stages. In our study, we found that farmers continue to make adoption decisions that ignore the concepts of innovations as static objects and the flawed Rogers assumption that once they made adoption decisions or reached confirmation, they will continue to do it the same way.

Moreover, farmers applied different types and intensities of production. Most farmers followed intercropping during the establishment of the AFI. Farmers intercropped to reap the dual benefits from crops and AFI. Intercropping was marginal in bamboo AFI due to the intrinsic nature of the AFI, where its roots are damaged during harvesting. Regarding the application of inputs, some farmers, whether consciously for the AFI or the crop, applied fertilizers and managed intensively by hoeing and weeding. Few farmers also applied compost, manures, and litter to improve productivity. Most farmers made simple management, such as fencing, and left the AFI. Farmers continue to make adjustments to improve productivity, match their demands and make decisions that aim at spillover effects. For example, farmers planted acacia on plots that have become marginal or unproductive. Also, farmers changed the planting density and spacing between the trees due to market feedback. These dynamic decisions were ignored largely by previous AF or AFI research.

It is evident from the synthesis of the empirical findings that many variables influence AFI adoption contexts. The emergence and perpetuation of an AFI over incumbent production systems require that these factors be identified first. Following the identification of the factors, understanding the flow of innovation stages and the integration among the variables and components is essential (Hermans et al. 2013).

## 5.2. Reflections on research method, theoretical framework, and generalization

### 5.2.1. Reflection on research methods and analytical generalization

The systematic review combined with meta-analysis is applied to capture the current general knowledge on adopting innovations and AFI adoption studies in SSA for 2005-2019. Systematic literature review is the most rigorous and transparent review method. The most comprehensive literature review method exhibits explicit methodical details and results in a low risk of bias compared to the narrative, scoping, and rapid literature review methods (Grant and Booth 2009). PRISMA model was applied only for searching AFI adoption studies in SSA. Strictly following the PRISMA model diminished the opportunity of incorporating extended knowledge from diverse studies and reports. To improve the progress and incorporate the extended adoption knowledge, we did a scoping review to collect science and practice in the general adoption research and practice. Overall the systematic literature review synthesized knowledge related to the status and practice of AFI adoption research in SSA and compiled existing progress toward improving current adoption research practices (chapter 4.1). By further employing a meta-analysis, the literature identified the trend of the research focus, the most explored variables, the model frequently employed, and the general research focus. It further helped picture the general context of AFI adoption in SSA and outlined the gaps. Ultimately, with a combination of major theoretical developments and the research gaps identified, the systematic literature review led to the development of a more comprehensive analytical framework (Figure 4) befitting the assessment of adoption studies in smallholder contexts, whether AFI or agricultural innovations.

Given that decision to adopt AFI is family or individual specific, this dissertation applied a household survey as the primary research method to examine the factors affecting AFI adoption by smallholder farmers in Ethiopia as a case study of SSA farmers. The application of household survey and triangulation from focus group discussions with the support of historical data from key informants consolidates the position of this dissertation for generalization across smallholder farmers around the globe (UN 2005). Indeed, focus group discussions and key informant interviews were conducted to understand community level features and opinions that affect AFI adoption. Practices related to trend analysis and retrospective approaches of data application related to the length and breadth of information synthesized from the field can also serve as an input or trailblazer to other researchers conducted in other sectors, such as the IT sector.

A mixed-methods approach consolidated the discovery of the complex and interrelated factors influencing AFI adoption in a thoughtful technique. Study locations for the research were selected purposively due to the extensive production of AFI. Farmers' selection followed simple random sampling procedures to capture representative information and facilitate research output generalization. With the incorporation of three different AFI, the comparative and more broad research approach displayed the summarization of insightful information regarding farmers' AFI woodlots adoption decision contexts.

The four discrete empirical results present a specific adoption context of smallholder farmers. To undertake a comprehensive assessment, we first developed an analytical framework. The framework details the categories and variables contributing to the ultimate AFI adoption decision. Rigorously the various factors are explained, graphically depicted, and computed against the AFI adoption decision. Besides applying a mix of methods to each output (chapters 4.2-4.5), the dissertation applied different analytical tools, such as various regression models (e.g., seemingly unrelated regression), to appraise previous adoption, assess current practices, and predict prospective adoption likelihood. With the examination of follow-up adoptions, the study filtrates the enabling and disabling factors for further adoption, even among initial adopters. By detailing such information, the dissertation was also able to illustrate differences among farmers in a quasi-experimental style over periods of adoption. The dissertation provided superior information by comprehensively highlighting temporal factors affecting AFI adoption compared to a cross-sectional analysis.

To improve uncertainty regarding AFI adoption influencing factors, the thematic based qualitative analysis provided backup information to integrate community broad information. Contrasting opinions and perceptions on the importance of market opportunities, effects on food availability, and positive and adverse spillover effects circuitously reinforce the outputs of quantitative, particularly regression, analysis approaches. Regarding analytical generalization, despite the scope of the study localized in Ethiopian mid-highland contexts, the research is generalizable for similar contexts. Applying simple random sampling procedures and statistical tools, including various econometric models, lends itself to generalization to similar contexts (UN 2005; Nuthall and Old 2018).

### 5.2.2. Reflection on the theoretical framework and theoretical contribution

Regarding theoretical aspects, this dissertation contributes to the development and broader application of a comprehensive conceptual framework that facilitates insightful (i.e., fine details and all perspectives) investigation of factors affecting innovation adoption. The comprehensive literature assessment opened up intuitive information on the broader contexts, with diverse perspectives and focus intensity, affecting the adoption of AFI and the broader innovation adoption practice. Despite the difference in focus, we understood that the adopters, the organizations that facilitate the delivery of the innovation, including its marketability and the intrinsic attributes perceived by the farmers, are essential. Beyond these individual factors, the integration and linkage among the actors are also vital for effective innovation adoption. After learning from the general conceptual and practical application of adoption concepts, including from empirical research in SSA, we understood that it is critical to consider all the actors and resources equivalently for effective AFI adoption. Based on these insights, we developed a comprehensive conceptual framework (Figure 4). The framework summarizes the components into three major groups, household contexts (adopters' contexts, numbers 1 and 2 of Figure 4), the innovation characteristics (perceived attributes, numbers 3 and 4 of Figure 4), and the system level features (institutional support systems, number 5 of Figure 4). Besides, we encouraged envisioning a holistic or systemic view, as expressed in number 6 of Figure 4. Overall our initial contribution to theory is the development of this conceptual framework.

The comprehensive conceptual framework builds on previous analytical frameworks. It largely contributes to (a) the improvement of the frequently employed diffusion of innovation theory, (b) the embodiment of the parsimonious (i.e., original) theory of planned behavior, (c) embracing innovation fluidity, (d) asserts dynamism of decisions, (e) tracks innovation flow path and (f) the identification of integration among factors and functions. The conceptual framework facilities and visualizes the option of conducting discrete and holistic adoption research and even evaluating the performance of the innovation system. The analytical framework is also adaptable to various sectors beyond the AFI sector, researching factors facilitating adoption.

Firstly, we contribute to the embodiment and improvement of the diffusion of innovations theory. Diffusion of innovations (Roger 1983; 2003) is still a prevalent theory, and we proved that the primary assumption that the adopters, institutions and the perceived attributes of the innovations broadly influence the adoption of innovations. The developed framework depicts adoption as influenced by three main components, which align with the major components of the diffusion of innovations theory. The alignment between enduring conceptual thoughts and empirical findings confirms that Rogers's propositions are imperative. Yet Rogers failed short of incorporating the psychological perspectives, wrongly perceived an innovation as a static object, and thought the first adoption decision after passing the famous five stages was the ultimate decision. Moreover, the adoption rate is not influenced by the perceived attributes alone; instead, all factors influence the rate and intensity of adoption. To consolidate its position as a foundational theoretical framework, required improvements beyond previously suggested (e.g., Hoffman 2007) in the above specified aspects are introduced, and we discuss these improvements in detail as part of the broader contributions of the dissertation.

Secondly, the dissertation contributes to the inclusion and embodiment of the theory of planned behavior. Intrinsic factors were depicted as necessary as extrinsic factors and are less explored in AFI adoption research (Meijer et al. 2015; Buyinza et al. 2020). We explored the influence of psychological constructs on AFI adoption and proved that psychological constructs are vital for making AFI adoption. Initially, additional constructs beyond the original three constructs (i.e., attitude, perceived behavior control, and subjective norms) were incorporated. Ultimately, only the original constructs were significantly associated with AFI adoption (Amare and Darr 2022). By doing this analysis, we contributed to this theory by displaying the application of the theory in AFI and the larger agricultural adoption research and by proving that the parsimonious theory of planned behavior (Ajzen 2010) is sufficient and its extension in the context of AFI adoption is unnecessary (Amare and Darr 2022).

Thirdly, we contribute to the notion that innovation is a fluid assembly that can be modified. Often research conceives innovation as a fixed object that is transferred by the innovators or actors and will be either adopted or abandoned. Farmers are usually given the AFI (i.e., seedlings) with single recommendations to implement during production. Based on our research, we understood that farmers continue to test or adjust the AFI to fit their market needs. Farmers changed the extent of adoption. They changed the planting density, altered the spacing between the plants, and designed the plantation to achieve the market desire. Beyond changing the initially recommended AFI quantity, farmers usually change the packages or components such as type and quantity of inputs utilized for production (e.g., fertilized, manured, composting), management types (e.g., fencing, hoeing, weeding or no weeding) and adjust the AFI to fit their specific needs (e.g., planting in high densities or otherwise). Such modifications influence the profitability and purpose of the AFI and ultimately impact the intensity of AFI adoption and hence the follow-up adoptions. Therefore, by first embracing the idea from commentaries (e.g., Glover et al. 2016), and practicing in our field research (Chapter 4.5), we contribute to developing a disruptive concept in the adoption of AFI and beyond. Comprehending at such extents is vital to understand better factors affecting adoption research, and aiming at increasing opportunity for modification is essential to have successful adoption development action ultimately. We essentially encompass emergent, iterative, and incremental changes (Glover et al. 2016) to the innovation itself happening over time due to the necessary adjustments to fulfill market demands, home consumption needs, or other purposes. To capture the fluid assembly concept of an innovation, the final adoption decision is depicted as the diversity of adoption decisions as farmers will modify the initial adoption, maintain initial packages, make follow-up adoptions of different magnitudes, or abandon it.

Fourthly, we embrace the notion that the adoption decision is dynamic. Empirical research in AFI assumes that farmers either make adoption or abandon it (e.g., Abiyu et al. 2016). Rogers (1983) states that farmers make adoption decisions after proceeding through the five stages, from knowing the existence of the innovation to implementation. After these stages, Rogers assumes that either farmers continue to implement or abandon it. By and large, the empirical research and the existing theoretical frameworks echo similar static decisions once farmers make an adoption. This dissertation proved that farmers either make follow-up adoptions or abandon further implementation. If farmers make follow-up adoptions, these decisions might proceed either reduced, maintained, or increased directions. Changes in the course or intensity of successive decisions beyond altering aspects of the initial package depend on previous adoption decisions (chapter 4.2). Overall, farmers' initial adoption decision does not necessarily reflect their final or enduring decision; instead, farmers make adoption decisions of varying directions. In so doing, we visualized the adoption path. We brought to light the consciousness of the researchers that incorporating this aspect of the adoption decision, process analysis (Fellows 1958), is essential for a thoughtful understanding of the contexts affecting AFI adoption.

Fifth, this dissertation contributes to the cognizance of the next moves of the farmers, whether it is a fully harvestable innovation like acacia AFI or longstanding like eucalyptus AFI. We retrieved the temporal adoption decisions of farmers (chapters 4.2, 4.4, and 4.5). Despite an initial interest in the adoption trend for a decade, we changed the intent and tried to understand the farmers' five successive adoption decisions. A good proportion of farmers made follow-up adoption for the second and third times. A negligible number of farmers undertook the fourth and fifth round adoption of the respective AFI (chapter 4.2, Figure 2). The research uncovered the omitted image of whether farmers make adoption for a few years and then abandon it or farmers use it on an ongoing basis. The empirical research delivered that farmers either test and abandon afterward or adopt persistently due to farmers' interest and coppicing features of the AFI. We disrupted traditional adoption research by revealing the depth of follow-up adoption decisions of farmers.

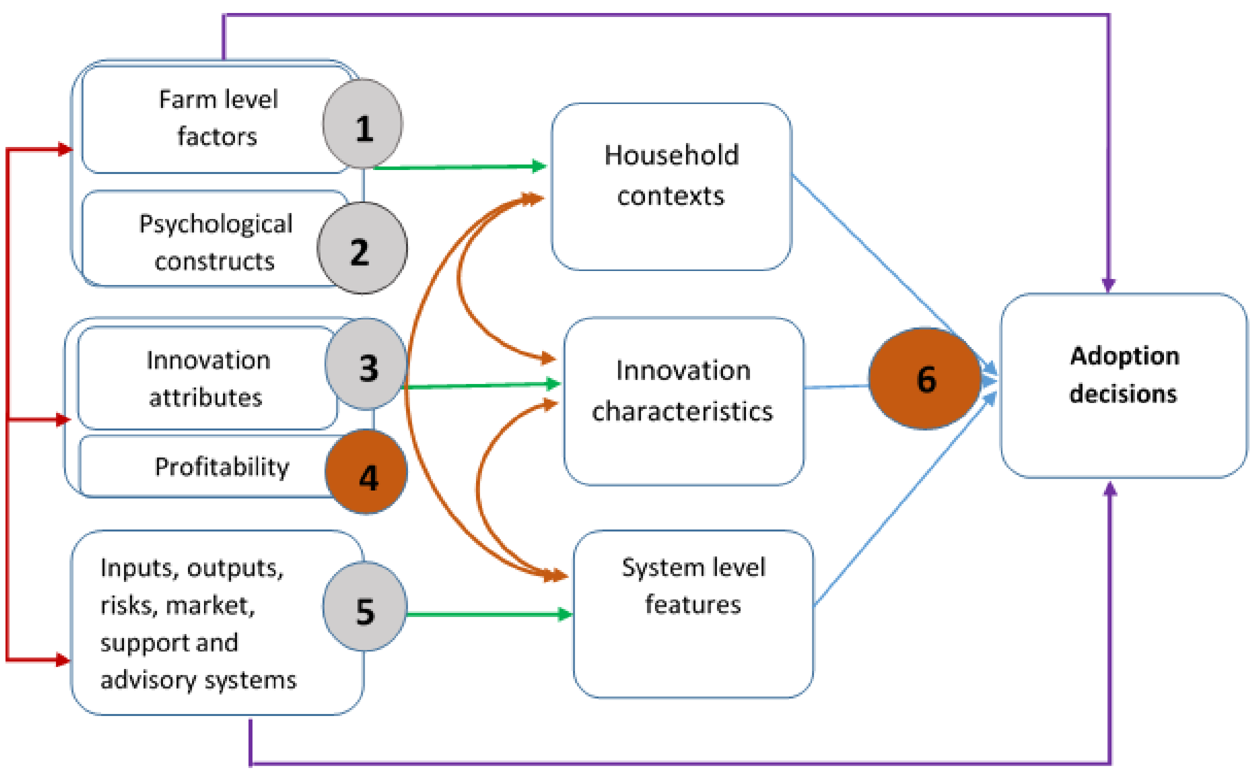


Figure 4. modified AFI adoption conceptual framework (orange colored numbers, 4 (profitability) and 6 (holistic) represent research perspectives not covered in this dissertation)

The framework further elaborates on the integration (redline arrows at the left of Figure 4) among factors/actors and categories of variables. Integration of actors is vital for the smooth flow of the innovation from adaptation to final implementation. In the delivery of the innovation, the technical skills, organizing and awareness creation, monitoring the implementation, and getting and responding to concerns and feedback influence the final adoption decision. Collaboration among actors or functions is hence as essential as the innovation itself. During empirical analysis, the integration can be discovered either by qualitative thematic analysis or stakeholder analysis, where the functions are displayed and evaluated towards the final adoption. Quantitatively this integration can be evaluated by testing the simultaneous effect of different variables. To exhaust the confounding effects of different variables on the ultimate adoption, we presented the evaluation of interdependencies among factors. By enabling the identification of individual and combined effects, the research illustrated the possibility for policymakers and practitioners to focus on specific links and actors for a more profound development success.

Our research facilitates discrete and holistic adoption research. It further enables evaluation of the performance of the innovation system (s). We further elaborate on this relationship. For the holistic analysis, the direct flow of the arrows represents this relationship. The three bigger-box plots at the left indicate the homogenous group of variables categorized under a single component of the three compartmentalized variables (Amare and Darr 2020). The green lines indicate the category in which these underlying variables belong. For example, psychological constructs (i.e., attitude, subjective norms, and perceived behavioral control) and socioeconomic and plot features are the two main sub-categories that form the household contexts component. This household context is one of the three elements that affect adoption at the grand level. Blue colors indicating the flow from this and other components (i.e., system level features and innovation characteristics) represent the principal holistic components affecting the adoption of AFI. Analysis of factors influencing AFI adoption at this stage represents a holistic view of analysis. In addition to the direct influence of these groups of components on the dependent variables, it is necessary to identify potential interdependencies among them. Potential investigation of this relationship during this holistic analysis is expressed by using the orange colored arrows. Individual root variables (e.g., farm level factors) are examined directly with the ultimate adoption decision. These variables, however, are comprised under household contexts that include the psychological perspectives of farmers. So, whether a researcher investigates the farm level factors, psychological constructs, or combined household contexts against AFI adoption, the researcher is doing discrete adoption research (purple colors, Figure 4). However, suppose the researcher aims at a combined, proper analysis of the effects of household contexts, system level features, and innovation attributes against AFI adoption. In that case, the researcher is conducting a holistic analysis, mimicking a systemic view.

Additionally, researchers might evaluate the performance of the innovation system (Tigabu 2017). Researchers can employ the framework to evaluate which innovation systems are performing better based on initially practiced intervention components. We believe that our research approach, the iterative learning and practicing approach, and the empirical results disrupt conventional adoption research, especially in the context of smallholder farmers, and lead to more insightful research with presumably thoughtful recommendations and tangible effects on policy and actions.

The research also improved the visualization of the adoption framework through a simplified yet self-depicting graphical representation. It depicts the influence of individual factors and categories of factors on AFI adoption, displays the integration possibility among variables and categories of variables, and illustrates systems or a holistic view. The conceptual framework generally applies to a wide array of sectors and innovations since it equivalently visualizes the innovation, the support system, and the adopters, including their integration. As briefly expressed, the framework is depictive of panel data, process, and holistic perspectives and is worthy of application in contexts of undertaking adoption studies aiming at consumers, innovation, and institutional levels.

## 5.3. Outlook and suggestions

This dissertation embraces concerns about the adoption problem in SSA, as iterated by Glover et al. (2016). With increased roles in the household economy, whether as a natural resource management option or a commercial product that facilitates value addition, research has continued since the 1970s to discover factors affecting smallholder AFI adoption decisions. The main body of this dissertation focused on understanding and revealing the complex factors affecting the AFI adoption decision of smallholder farmers in Amhara region of Ethiopia. The outputs of adoption research in this geographic area are inconsequential (Glover et al. 2016). Accordingly, this dissertation aimed to address the knowledge gap related to the AFI adoption problem in the context of smallholder farmers, with Ethiopian smallholders as a case study by employing an iterative process of identifying gaps, learning previous practices, and filling the gap strategy of iterative learning-practice process.

By attempting to narrate and quantifiably explore the dynamics of adoption decisions, we go past the precarious outputs of regular adoption research and provide actionable recommendations in science and practice. The tendency to explore similar variables in a seemingly approving approach and ignore site specific, perspective widening contexts and hence monotonous approach and fragmented information deters the possible improvement of development actions and policy designs.

### 5.4.1. Recommendations for future research

We employed both conventional and robust research methods based on the assumption that classical economic adoption studies failed to address the complete adoption problem. Beyond including more behavioral and holistic methods, we employed a retrospective data set to address the issue adequately. Exercising this type of research on food and other sector AFI is important to address more fundamental issues related to food security and livelihood improvement or climate adaptation. In our context, we could not specifically account for the impacts of different land ownerships besides self-owned plots. It is suggested, therefore, to incorporate the effects of various land ownership conditions such as rent-in, rent-out, share-in, and share-out to avoid confounding effects.

Given the results from this study, future studies should investigate the fitness of the developed 'AFI adoption framework', assess the profitability of AFI using real-option methods, employ both discrete investigations (such as isolated econometric models) for specific purposes (e.g., when development practitioners are fixed their innovations are characteristically compatible and preferred by the local community and appropriate organization support is available but don't know/understood what farmers or farm family features/contexts facilitate or impend or likely adopt the innovations) to foster pacemaker adoptions. The AFI adoption framework provides the platform to visualize the integration of different factors. However, the inability of the framework to integrate the specific functions as depicted by (Hekkert et al. 2007), and the poor effect prediction of Bayesian tools lends us to ask for refinement of the 'AFI adoption framework'. We further encourage the refinement of the developed analytical framework, especially by adopting traditional AFI and agricultural technologies.

### 5.4.2. Development and policy recommendations

In our study, we proved that farmers are attracted to adopting AFI. Based on these results, we suggest the following points for consideration in future development and policy actions.

**Development actors or extension agents:** development actors should not be naïve enough that satisfaction with certain or (partially) conditions does not lead to the automatic adoption of AFI. Instead, the innovation characteristics, including its adaptability and compatibility to the local farming conditions, home consumption needs, the prevailing market opportunities, the type and intensity of organizational supports, the focus of the government, and the resources and features of the farm family, all influence the final adoption. Moreover, farmers might make follow-up adoption decisions varyingly, such as increasing, decreasing, or equivalent intensity compared to their initial or previous adoption extents. Also, taking note of the importance of each factor at different stages of adoption is essential.

**Policymakers:** Besides preferring more profitable AFI, farmers think of their impact on home consumption needs, local food availability, and other side effects. While these notions can be debated, policymakers must ratify appropriate policy regulations to monitor and timely respond to such issues. In market-oriented productions such as woodlots, the factors affecting further adoption relate to system level features (i.e., away from initial farm level factors). Thus, policy regulators should design policy or support systems to aid follow-up or consecutive adoption decisions. Moreover, price volatility, as is often the case for agricultural products, is a big issue. Locating new markets, introducing skills improvement for new product development that competes with an alternative or new products, or diverging the market saturation problem are necessary policy steps.

## 5.5. Limitations of the study

Despite employing retrospective data, a proxy for temporal data, recall problems mainly related to input and output for traditional crop production limited the robustness of the data. Also, the analysis could have benefited by employing time-series econometric models if the follow-up AFI adoptions occurred continuously. Nonetheless, the follow-up AFI adoptions largely occurred irregularly, one after the other, not on continuous (uninterrupted) calendar years or farm production seasons. The rule of thumb of a maximum of 13 variables in econometric models also limited the possibility of inserting and executing a larger number of variables in econometric models.

Exploring the integration among factors and actors is an essential component of adoption research that aims to contribute to development and policy or make an impact profoundly. Due to the voluminous nature of this dissertation, the AFI adoption components related to profitability and holistic analysis are excluded. However, prospective research is suggested to undertake profitability analysis by employing tools that examine various production options such as fertilized management, intercropping options, expansion, and contraction options. A preliminary test of the removed profitability chapter showed a tangible application of the real-options approaches financial appraising tool. We encourage holistic investigations to broaden the scope of understanding. Further, we are unable to present and discuss thoroughly the re-inventions aspects of innovation modification by farmers, except limited descriptions in the system level features.

This study clearly lacks a cross-country comparison to represent the SSA landscape and farmers. Initially, the research aimed at generating information related to AFI adoption under smallholder contexts. Consequently, it largely represents smallholder farmers' mid-highland and highland or wet contexts. Despite incorporating three woodlot AFI, this research is far from representative of the traditional AFI commonly produced by farmers. It further ignores the complex integration or interface among AFI and farmers' larger farming or livelihood activities. This dissertation is further limited to providing sound triangulation information from actors as a stakeholder workshop was not conducted due to impossibility related to COVID-19 contexts, information shortage on stakeholder profiles, and budget and time constraints.

REFERENCES

Abiyu, Abrham; Teketay, Demel; Gratzer, Georg; Shete, Maru (2016): Tree Planting by Smallholder Farmers in the Upper Catchment of Lake Tana Watershed, Northwest Ethiopia. In Small-scale Forestry 15 (2), pp. 199–212. DOI: 10.1007/s11842-015-9317-7.

Ajayi,O. C., Akinifesi, F. K., Mitti, J. M., de Wolf, J., Matakala, P.,2008. Adoption, Economics and Impact of Agroforestry technologies in southern Africa. In: D. R. Batish, R. K. Kohli, S. Jose, H. P. Singh (Eds.), Ecological basis of Agroforestry:343-360. Taylor and Francis Group/CRC Press, FL.

Ajibade, Patrick, "Technology Acceptance Model Limitations and Criticisms: Exploring the Practical Applications and Use in Technology-related Studies, Mixed-method, and Qualitative Researches" (2018). Library Philosophy and Practice (e-journal). 1941.

Ajzen, Icek (1991): The theory of planned behavior. In Organizational Behavior and Human Decision Processes 50 (2), pp. 179–211. DOI: 10.1016/0749-5978(91)90020-T.

Ajzen, Icek (2011): The theory of planned behavior: reactions and reflections. In Psychology & health 26 (9), pp. 1113–1127. DOI: 10.1080/08870446.2011.613995.

Altieri, M., 2004.Linking ecologists and traditional farmers in the search for sustainable agriculture.Frontiers in Ecology and the Environment 2, 35-42.

Amare Dagninet, Darr Dietrich (forthcoming) Can a sequential analysis provide a more robust understanding of farmers' adoption decisions? An example from an agroforestry adoption study in Ethiopia.

Amare, D., Mekuria, W., T/wold, T., Belay, B., Teshome, A., Yitaferu, B., Tessema,T. Tegegne, B.,2016. Perception of local community and the willingness to pay to restore church forests: the case of Dera district, northwestern Ethiopia, Forests, Trees and Livelihoods.

Amare, Dagninet, Wondie, Menale, Mekuria, Wolde, Darr, Dietrich, 2019. Agroforestry of smallholder farmers in Ethiopia: practices and benefits. Small-scale For. 18 (1),39–56.

Amare, Dagninet; Darr, Dietrich (2020): Agroforestry adoption as a systems concept: A review. In Forest Policy and Economics 120, p. 102299. DOI: 10.1016/j.forpol.2020.102299.

Amare, Dagninet; Mekuria, Wolde; Belay, Beyene (2017): Willingness and Participation of Local Communities to Manage Communal Grazing Lands in the Lake Tana Biosphere, Ethiopia. In Society & Natural Resources 30 (6), pp. 674–689. DOI: 10.1080/08941920.2016.1264649.

Avelino, F.,Rotmans, J., 2009. Power in transition: An Interdisciplinary Framework to Study Power in Relation to Structural Change. European Journal of Social Theory12, 543-569.

Aynalem Yechalework. 2019. Opportunities and Challenges of the Industrial Park Development in Ethiopia. Lessons from Bole Lemi and Hawassa Industrial Park, Munich, GRIN Verlag, https://www.grin.com/document/1183656.

Bakkabulindi Fred Edward K. (2014) A call for Return to Rogers' Innovation Diffusion Theory. Makerere Journal of Higher Education, 6 (1):55 – 85.

Bantihun Mehari, Abay; Abera, Melese Worku (2019): Opportunities and challenges of adopting home garden agroforestry practices in Ethiopia: A review. In Cogent Food & Agriculture 5 (1), p. 1618522. DOI: 10.1080/23311932.2019.1618522.

Belay, Beyene; Zewdie, Solomon; Mekuria, Wolde; Abiyu, Abrham; Amare, Dagninet; Woldemariam, Tadesse (2019): Woody species diversity and coffee production in remnant semi-natural dry Afromontane Forest in Zegie Peninsula, Ethiopia. In Agroforest Syst 93 (5), pp. 1793–1806. DOI: 10.1007/s10457-018-0285-8.

Birhane, Emiru.2019. agroforestry governance in Ethiopia. Final Report. Consultancy report, 50pages.

Buyinza, Joel; Nuberg, Ian K.; Muthuri, Catherine W.; Denton, Matthew D. (2020): Psychological Factors Influencing Farmers' Intention to Adopt Agroforestry: A Structural Equation Modeling Approach. In Journal of Sustainable Forestry 39 (8), pp. 854–865. DOI: 10.1080/10549811.2020.1738948.

Chuttur, Mohammad, " Overview of the Technology Acceptance Model: Origins, Developments and Future Directions" (2009). All Sprouts Content. 290.

Cochran, W. G.,1977. Sampling techniques (3rd ed.). New York: John Wiley & Sons.

Coe, R., Sinclair, F., Barrios, E., 2014. Scaling up Agroforestry requires research 'in' rather than 'for' Development. Current Opinion in Environmental Sustainability, 6:73–77.

Cramb, R.A, 2016. Processes Influencing the Successful Adoption of New Technologies by Smallholders.

Darr, D., 2008. Effective even when neglected: Farmer groups and the diffusion of agroforestry innovations in rural communities of Eastern Africa. A PhD dissertation submitted to University of Dresden.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 13(3), 318–339.

Dwivedi, Yogesh K; Rana, Nripendra P.; Jeyaraj Anand; Clement, Marc; Williams, Michael D. 2019. Re-examining the Unified Theory of Acceptance and Use of Technology (UTAUT): Towards a Revised Theoretical Model. Inf Syst Front, 21:719–734.

Endale, Bekele Jiru (2019): Review on Agro-forestry System and Its Contribution in Ethiopia. In IJSMIT 5 (1), p. 8. DOI: 10.11648/j.ijsmit.20190501.12.

FAO (2020): Agroforestry:Definition. Available online at http://www.fao.org/forestry/agroforestry/80338/en/, checked on 8/7/2020.

Fekadu, M., Muchie, M., Worku, Z., 2014.Determinants of agroforestry technology adoption in Eastern Cape Province, South Africa.Development Studies Research:An Open Access Journal, 1:1, 382-394.

Fellows, I. F., 1958. Using Process Analysis to Improve Farm Organization. Journal of Farm Economics, 40(5),1418.

Fishbein, M.,& Ajzen, I. (1975). Belief, attitude, intention, and behavior: An introduction to theory and research. Reading: Addison-Wesley Publication Company.

Gibson, John; Kim, Bonggeun, 2005. Can we trust retrospective recall to replace panel data? Available online at https://www.researchgate.net/publication/228431326.

Glover, Dominic; Sumberg, James; Andersson, Jens A. ,2016.The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. In Outlook Agric 45 (1), pp. 3–6.

Grant, Maria J.; Booth, Andrew (2009) A typology of reviews: an analysis of 14 review types and associated methodologies. Health Information and Libraries Journal, 26:91–108.

Harrington, L., Tow, P., 2012. Types of rainfed farming systems around the world. Rainfed Farming Systems, 45-74.

Harrison, Steve; Herbohn, John ,2016. Financial Evaluation of Forestry Investments: Common Pitfalls and Guidelines for Better Analyses. In Small-scale Forestry 15 (4), pp. 463–479. DOI: 10.1007/s11842-016-9334-1.

Hekkert, P., Suurs, A., Negro, O., Kuhlmann, S., Smits, M., 2007.Functions of innovation systems: A new approach for analyzing technological change. Technological Forecasting & Social Change, 74 (2007):413–432.

Hermans, Frans; Stuiver, Marian; Beers, P. J.; Kok, Kasper (2013): The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. In Agricultural Systems 115, pp. 117–128. Available online at DOI: 10.1016/j.agsy.2012.09.006.

Hillmer, U. (2009). Existing Theories Considering Technology Adoption. In: Technology Acceptance in Mechatronics. Gabler.

Hoffman, Voker (2007): Book Review. In The Journal of Agricultural Education and Extension 13 (2), pp. 147–158. DOI: 10.1080/13892240701289601.

Jamala, G., Shehu, E., Yidau, J., Joel, L., Factors Influencing Adoption of Agro-Forestry amongSmallholder Farmers in Toungo, South-eastern, Adamawa State,Nigeria. Journal of Environmental Science, Toxicology and Food Technology, 6, (6):66-72.

Jerneck, A.,Olsson, L., 2013.More than trees! Understanding the Agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya.Journal of Rural Studies, 32:114-125.

Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, 76: 1-10.

Kim Youngseek; Crowston, Kevin. 2011.Technology Adoption and Use Theory Review for Studying Scientists' Continued Use of Cyber-infrastructure. ASISIT 2011, New Orleans, USA

Kiptot, E., Franzel, S., Hebinck, P., Richards, P., 2006.Sharing seed and knowledge: farmer to farmer dissemination of Agroforestry Technologies in western Kenya.Agroforestry Systems, 68: 167-179.

Koul, Sahil; Eydgahi2, Ali. 2017. A systematic review of technology adoption frameworks and their applications. J. Technol. Manag. Innov., ,12(4):106-113.

Leeuwis, C., Van den Ban, A., 2004. Communication for Rural Innovation:Rethinking Agricultural Extension. Oxford: Blackwell.

Lubell, Mark; Niles, Meredith; Hoffman, Matthew (2014): Extension 3.0: Managing Agricultural Knowledge Systems in the Network Age. In Society & Natural Resources 27 (10), pp. 1089–1103. DOI: 10.1080/08941920.2014.933496.

Mbow, C., Noordwijk, M.,Prabhu, R.,Simons, T., 2014.Knowledge Gaps and Research Needs Concerning Agroforestry's Contribution to Sustainable Development Goals in Africa.Current Opinion in Environmental Sustainability, 6:162–170.

MEFCC (Ministry of Environment, Forest and Climate Change. 2018. National Forest Sector Development Program, Ethiopia.MEFCC, Volume III: Synthesis Report. Addis Ababa, MEFCC: 117.

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W. &Nieuwenhuis, M.,2015. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa, International Journal of Agricultural Sustainability, 13:1, 40 -54, DOI: 10.1080/14735903.2014.912493.

Mellor John W. Dorosh Paul (2010) Agriculture and the Economic Transformation of Ethiopia. Development Strategy and Governance Division, International Food Policy Research Institute – Ethiopia Strategy Support Program 2, Ethiopia.

Mercer, D., 2004. Adoption of Agroforestry innovations in the tropics: a review. Agroforestry Systems, 61: 311-328.

Mercer, D.E., Miller, R.P., 1998. Socioeconomic research in agroforestry: Progress, prospects, priorities. Agrofor. Syst. 38, 177–193.

Montambault, J., Alavalapati, J., 2005. Socioeconomic research in agroforestry: a decade in review. Agroforestry Systems, 65: 151-161.

Mutambara, J, Dube, V.,Mvumi, M. 2012. Agroforestry technologies involving fodder production and implication on livelihood of smallholder livestock farmers in Zimbabwe. A Case Study of Goromonzi District.Livestock Research for Rural Development, 24:11.

Nair, P., 2011. Agroforestry systems and environmental quality: introduction. Journal of Environmental Quality, 40: 784-790.

Nigatu, Amsalu; Wondie, Menale; Alemu, Asmamaw; Gebeyehu, Dagnachew; Workagegnehu, Hiwot (2020): Productivity of highland bamboo (Yushania alpina ) across different plantation niches in West Amhara, Ethiopia. In Forest Science and Technology 16 (3), pp. 116–122.

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Nohmi, Makoto; Tsubo, Mitsuru et al. (2017): Factors Affecting Small-Scale Farmers' Land Allocation and Tree Density Decisions in an Acacia decurrens-Based taungya System in Fagita Lekoma District, North-Western Ethiopia. In Small-scale Forestry 16 (2), pp. 219–233. DOI: 10.1007/s11842-016-9352-z.

Nigussie, Zerihun; Tsunekawa, Atsushi; Haregeweyn, Nigussie; Adgo, Enyew; Tsubo, Mitsuru; Ayalew, Zemen; Abele, Steffen (2020): Economic and financial sustainability of an Acacia decurrens-based Taungya system for farmers in the Upper Blue Nile Basin, Ethiopia. In Land Use Policy 90, p. 104331. DOI: 10.1016/j.landusepol.2019.104331.

Nuthall, P. L.; Old, K. M. ,2018. Intuition, the farmers' primary decision process. A review and analysis. Journal of Rural Studies, 58:28–38.

Panzano, P. C.; Roth,D. (2006)The decision to adopt evidence-based and other innovative mental health practices: Risky business? Psychiatric Services, 57(8), 1153–1161. doi: 10.1176/appi.ps.57.8.1153.

Park CS, Lee S, Kim H, Kabak M.2022. Diffusion of Innovations-Informed Knowledge Translation Strategy to Implement Optimal Safe Nursing Workforce Policy in Practice. Florence Nightingale J Nurs., 30(1):92-99.

Partey, Samuel T.; Sarfo, Daniel A.; Frith, Oliver; Kwaku, Michael; Thevathasan, Naresh V. (2017): Potentials of Bamboo-Based Agroforestry for Sustainable Development in Sub-Saharan Africa: A Review. In Agric Res 6 (1), pp. 22–32. DOI: 10.1007/s40003-017-0244-z.

Pattanayak, S., E. Mercer, D. Sills, E. Yang, J., 2003.Taking stock of Agroforestry adoption studies. Agroforestry Systems, 57:173-186.

Raffaele, V., Harvey, C., Pavel, B.S., Avelino, J., Rapidel, B., Donatti, C., Martinez, R.,, 2015. Ecosystem-based adaptation for smallholder farmers: Definitions, opportunities and constraints. Agriculture, Ecosystems and Environment, 211:126–132.

Reubens, B., Moeremans, C., Poesen, J., Nyssen, J., Tewoldeberhan, S., Franzel, S., Deckers, J., Orwa, C., Muys, B., 2011. Tree species selection for land rehabilitation in Ethiopia: from fragmented knowledge to an integrated multi-criteria decision approach. Agroforestry Systems, 82: 303-330.

Richard, C., Sinclair, F., Barrios, E., 2014. Scaling up Agroforestry requires research 'in' rather than 'for' development. Current Opinion in Environmental Sustainability, 6:73–77.

Rogers, E. M. (1962): Diffusion of Innovations. 1st edition. New York: The Free Press.

Rogers, E. M. (1983): Diffusion of Innovations. 3rd edition. New York: The Free Press.

Rogers, E. M., 2003. Diffusion of Innovations.5th edition. New York: Free Press.

Sahin, Ismail (2006) Detailed Review of Rogers' Diffusion of Innovations Theory and Educational Technology-Related Studies Based On Rogers' Theory. TOJET 5 (2), article 3.

Smith, S. ,Mbow, C., 2013. Editorial overview: Sustainability challenges: Agroforestry from the past into the future. Current Opinion in Environmental Sustainability, 6:134–137.

Sood, K., Najiar, C., Singh, A., Handique, P., Singh, B. and Rethy, P., 2008. Association Between Socio-economic parameters and Agroforestry Uptake: Evidence from Eastern Himalaya. Indian Journal of Forestry, 31(4):559-564.

Taherdoost, Hamid. 2018. A review of technology acceptance and adoption models and theories. Procedia Manufacturing, 22:960–967.

Tefera, Berihun; Kassa, Habtemariam (2017): Trends and Driving Forces of Eucalyptus Plantation by Smallholders in the Lake Tana Watershed of Ethiopia. In Krystyna Stave, Goraw Goshu, Shimelis Aynalem (Eds.): Social and Ecological System Dynamics. Cham: Springer International Publishing (AESS Interdisciplinary Environmental Studies and Sciences Series), pp. 563–580.

Telora, B.T., Pretzsch J., Kassa. H., and Darr D. 2021. Cluster analysis for forest and wood-processing industry sector development in Ethiopia. Ph.D. dissertation submitted to TU Dresden.

Tigabu, Aschalew Demeke (2017) Analysing the diffusion and adoption of renewable energy technologies in Africa: The functions of innovation systems perspective, African Journal of Science, Technology, Innovation and Development, DOI:10.1080/20421338.2017.1366130.

UN,2005. Household Sample Surveys in Developing and Transition Countries. Department of Economic and Social Affairs, Statistics Division Studies in Methods Series F No. 96, New York.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. Management Science, 46(2), 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425–478.

WB (2022) The World Bank Annual report 2021: Ethiopia. https://data.worldbank.org/country/ET.

Williams, Michael D., Rana Nripendra P., Dwivedi Yogesh K. (2015). The unified theory of acceptance and use of technology (UTAUT): a literature review", Journal of Enterprise Information Management, 28 (3): 443 - 488

Wisdom Jennifer P.; Chor, Ka Ho Brian; Hoagwood, Kimberly E.; Horwitz, Sarah M. (2013) Innovation Adoption: A Review of Theories and Constructs. Adm Policy Ment Health, 1-23.DOI 10.1007/s10488-013-0486-4.

Wondie, Menale; Mekuria, Wolde (2018): Planting of Acacia decurrens and Dynamics of Land Cover Change in Fagita Lekoma District in the Northwestern Highlands of Ethiopia. In Mountain Research and Development 38 (3), pp. 230–239. DOI: 10.1659/MRD-JOURNAL-D-16-00082.1.

Yadeta, Hundessa Adugna;Ayana, Alemayehu Negassa (2020)The Current Practices and Gaps in Forest Accounting System of Ethiopia: A Review. Research Journal of Finance and Accounting, 11(19), 2020.

Zerssa, G.; Feyssa, D.; Kim, D.-G.; Eichler-Löbermann, B.Challenges of Smallholder Farming in Ethiopia and Opportunities by Adopting Climate-Smart Agriculture. Agriculture 2021, 11, 192. https://doi.org/10.3390/agriculture11030192.

Zhang Xiaodi, Tezera Dejene, Zou Ciyong, Wang Zhen, Zhao Jie, Gebremenfas Eneyew Abera, Dhavle Jaidev (2018) Industrial park development in Ethiopia Case study report. United Nations Industrial Development Organization, Department of Policy, Research and Statistics. Working Paper 21/2018. Vienna.

# APPENDICES

## Appendix A: Supplementary files of Chapter 4.1

Table 1. Keywords used for searching relevant AF literature (Search dates 03-05 July 2019)

| Key word | Results (studies) | Key word | Results (studies) |
|---|---|---|---|
| agrofor* | 5,637 | agro-for* | 552 |
| agrofor* adoption | 418 | agro-for* adoption | 18 |

| | | | |
|---|---|---|---|
| agrofor* innovation | 124 | agro-for* innovation | 12 |
| agrofor* diffusion | 28 | agro-for* diffusion | No records |
| agrofor* livelihood | 497 | agro-for* livelihood | 27 |
| agrofor* tech* | 779 | agro-for* tech* | 99 |
| agrofor* soc* network | 46 | agro-for* soc* network | 9 |
| agrofor*extension | 178 | agro-for* extension | 18 |
| agrofor*advi* | 41 | agro-for* advi* | 2 |
| tree plant* small* | 9749 | woodlot* | 393 |
| tree plant* small* extension | 113 | woodlot* extension | 14 |
| tree plant* small* advi* | 24 | woodlot* advi* | 1 |
| farm forest* | 6203 | farm forest* extension | 147 |
| tree plant*extension | 650 | farm forest* advi* | 45 |
| tree plant*advi* | 181 | | |

*The selection process employed broad search mechanism (searching all literature types including articles, conference papers and all other grey literature)

Table 2. List of all literature used in this manuscript

| Qualitative AF studies (24) | Econometric AF adoption studies (58) | Reviews on AF adoption (6) | Literature making relevant conceptual contributions (20) |
|---|---|---|---|
| Ajayi et al 2011; Appiah and Pappinen 2010; Bucagu et al 2013; Chitakira et al 2010; Darr and Pretzsch 2008;Duguma 2013;Elias 2015; Foundjem-Tita et al 2013; Guteta and Abegaz 2018;;Isaac et al 2007; Ite 2005;Jerneck and Olsson 2013;Johannson et al 2013;Katanga et al 2007;Kiyani et al 2017; Lillesø et al 2011;Iiyama et al 2018; Mekoya et al 2008; Nyaga et al 2015;Molua 2005;Oduro et al 2018;Rahim et al 2007; Shackleton et al 2008;Sirrine et al 2010; | Abiyu et al. 2015;Admasu et al 2013;Akoto et al 2018; Akrofi-Atitianti et al 2018;Amare et al 2019;Basinger et al 2011;Bryan et al 2013;Call et al 2017;Chukwuone 2008; Conteh et al 2015;Coulibaly et al 2017;Deressa et al 2009;Etongo et al 2018; Fagariba et al 2018;Fahmi et al 2014; Fase and Grote 2014; Gabriel et al 2017; German et al 2009;Gibreel 2013;Gyau et al 2012;Gyau et al 2014;Gyau et al 2015;Haglund et al 2011;Haile et al 2016;Hitayezu et al 2016;Iheke and Agodike 2016;Iiyama et al 2107; Jenbere et al 2011;Kakhobwe et al 2016;Jera and Ajayi 2008;Kakuru et al 2014;Keil et al 2005;Kiptot 2008;Kiptot et al 2006;kiptot et al 2007;Mbosso et al 2015;Mponela et al 2016;Mukadasi et al 2007;Musa et al 2018;Nahayo et al 2016; Ndayambaje et al 2012;Ndayambaje et al 2013;Ndegwa et al | Mercer and Miller 1998; Pattanayak et al. 2003; Mercer 2004; Montambault and Alavalapati 2005; Meijer et al 2014; Partey et al. 2017 | Birhanu et al. 2017; Borremans et al. 2018; Danquah and Joseph 2017; Fisher and Kandiwa 2014; Fischer and Qaim 2012; Glover et al. 2016; Hekkert et al. 2007; Hermans et al. 2013; Khataza et al. 2018; Lambrecht et al 2014; Lybbert and Sumner 2012; Martini et al. 2017; Michalscheck et al. 2018; Micheels and Nolan 2016; Mutsvangwa-Sammie et al. 2017; Pamuk et al. 2014; Pannel et al 2006; Reed 2007; Sturdy et al. 2008; van Rijn et al. 2012<br><br>General supporting literature (9)<br>Bachewe et al. 2018; Dawson et al. 2016; Feder et al. 1985; Feder and Umali 1993; Harrison and Herbohn 2016; Hoffman 2007; Marra et al. 2003; Rogers 2003; Vanlauwe et al. 2014 |

| | | |
|---|---|---|
| | 2016;Ndongo et al 2010;Nigussie et al 2016;Nigussie et al 2018;Nkomoki et al 2018;Onu 2006;Osei et al 2018;Owombo and Idumah 2016;Rahim et al 2008;Sanginga et al 2006;Sanou et al 2017;Toth et al 2017;Toth et al 2017b;Wafulu et al 2015;Zeweld et al 2018;Zhang and Owiredu 2007 | |

Table 3. List of all variables included in econometric models and their significance

| Variables | Original variables consolidated into the concept | Number of studies/models that used the concept | Number of positive significant associations with AF adoption/ diffusion | Number of insignificant associations with AF adoption/ diffusion | Number of negative significant associations with AF adoption/ diffusion |
|---|---|---|---|---|---|
| Location | Location/district | 35 | 14 | 15 | 6 |
| Distance to market center | Distance to market center | 28 | 7 | 20 | 1 |
| Distance to government extension | Distance to government extension | 1 | 1 | 0 | 0 |
| Distance to town | Distance to town | 1 | 0 | 0 | 1 |
| Distance to school | Distance to school | 1 | 1 | 0 | 0 |
| Distance to health center | Distance to health center | 1 | 0 | 1 | 0 |
| Distance to plot | Distance to plot | 3 | 1 | 2 | 0 |
| Distance to main road | Distance to main road | 23 | 3 | 15 | 5 |
| Gender | Gender, sex, female head | 62 | 14 | 42 | 6 |
| Age | Age | 86 | 17 | 57 | 12 |
| Education | Formal education, school attendance, years of schooling | 78 | 23 | 49 | 6 |
| Family size | Family size | 55 | 13 | 41 | 1 |
| Dependency ratio | Dependency ratio | 5 | 0 | 5 | 0 |
| Labor | Active labor, total labor, available labor, access to hired labor, adult male, labor supply, labor weight | 41 | 9 | 28 | 4 |
| Village population | Village population | 11 | 5 | 6 | 0 |
| Marital status | Marital status | 6 | 0 | 5 | 1 |
| Farm experience | Farm experience, no of years in crop production | 13 | 5 | 1 | 7 |
| Farming as main occupation | Farming as main occupation | 9 | 4 | 5 | 0 |
| Farm size | Total owned, operated land, farm size, plot size, land size | 69 | 25 | 40 | 4 |
| Land on main farm block | Land on main farm block | 1 | 0 | 0 | 1 |
| Tenure security | Tenure length, family farm, tenancy, tenure security, ownership status, customary tenure | 20 | 8 | 11 | 1 |
| Wealth | Asset index, house type, wealth status, social class | 11 | 1 | 9 | 1 |
| Information access | Possession of cellphones, radios, information access index, media influence | 6 | 1 | 5 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Fragmentation | Fragmentation, no of plots | 9 | 1 | 6 | 2 |
| Water availability | irrigation practice, water availability, distance to water source | 7 | 1 | 6 | 0 |
| Diseases perception | pest problem perception, used pesticides, crop loss, livestock loss, AF diseases, trees die | 9 | 3 | 6 | 0 |
| Livestock | TLU/livestock ownership/size | 32 | 8 | 20 | 4 |
| Apiculture | Apiculture practice | 3 | 1 | 2 | 0 |
| Fattening | Fattening practice | 1 | 0 | 1 | 0 |
| Initial investment | Initial investment | 2 | 2 | 0 | 0 |
| Farm income | AF farm gate price, Farm income, income from AF | 24 | 5 | 16 | 3 |
| Off farm income | Off farm/nonfarm economic activity, off farm wage rate, non-farm employment, employment income | 43 | 12 | 26 | 5 |
| Credit | Access to/ amount of credit | 22 | 4 | 16 | 2 |
| Extension service | extension access/ contact, technical support | 44 | 15 | 26 | 3 |
| Farmer- to- farmer extension | Farmer- to- farmer extension | 1 | 1 | 0 | 0 |
| Training | Training | 6 | 1 | 5 | 0 |
| Demonstration | Demonstration | 2 | 0 | 2 | 0 |
| Community meetings | Community meetings | 2 | 0 | 2 | 0 |
| Field day | Field day, training centers presence, training centers performance | 4 | 2 | 1 | 1 |
| Field visit | Field visit | 2 | 0 | 2 | 0 |
| Trust | Trust | 1 | 0 | 1 | 0 |
| No of relatives | No of relatives in the locality | 1 | 0 | 1 | 0 |
| Collective action | Collective action | 1 | 1 | 0 | 0 |
| Structural social capital | Structural social capital | 1 | 1 | 0 | 0 |
| Bridging social capital | Bridging social capital | 2 | 1 | 1 | 0 |
| Agro-ecology | Altitude, agroecology | 3 | 3 | 0 | 0 |
| Temperature | Temperature | 3 | 1 | 2 | 0 |
| Precipitation | Precipitation | 4 | 2 | 1 | 1 |
| Membership to associations | Membership to associations, membership years | 35 | 11 | 22 | 2 |
| Boundary conflict | Conflict boundary | 5 | 3 | 2 | 0 |
| Incentives | Incentive from gov., subsidies, price of product, premium pricing | 14 | 1 | 11 | 2 |
| Benefit from agri. union | Benefit from agri union | 1 | 1 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Proportion of food from AF system | Proportion of food coming from AF system | 4 | 1 | 1 | 2 |
| Adoption experience | Adoption experience, planted bamboo before, adopted complementary tech, exposure | 15 | 8 | 4 | 3 |
| AF training | AF training | 3 | 3 | 0 | 0 |
| Input availability | Presence of nearby nursery/ availability, seed availability | 5 | 4 | 1 | 0 |
| Economically valued birds | Economically valued birds | 1 | 0 | 1 | 0 |
| Annual expenditure | Annual expenditure | 3 | 1 | 1 | 1 |
| Keeping trees on farms | Keeping trees on farms | 1 | 1 | 0 | 0 |
| Tree preferred | Type tree, preferred species | 1 | 0 | 0 | 1 |
| Primary objective for growing crops | Primary objective for growing crops | 1 | 1 | 0 | 0 |
| Crop preference | Crop preference | 1 | 1 | 0 | 0 |
| Regular cropping method | Regular cropping method | 1 | 0 | 0 | 1 |
| Meeting crop production target | Meeting crop products target | 1 | 1 | 0 | 0 |
| Soil fertility | Soil fertility challenges, possession of marginal land, productivity of the plot, soil texture, slope | 8 | 5 | 3 | 0 |
| Access to fertilizer | Access to fertilizer | 1 | 0 | 1 | 0 |
| Knowledge | Knowledge on bamboo as fodder, perceived usefulness, favorable attitude, use of bamboo, knowledge on bamboo charcoal/AF | 16 | 2 | 11 | 3 |
| Livestock feed experience | Livestock feed used bamboo before | 1 | 0 | 0 | 1 |
| Beliefs system | Taboos/beliefs associated with planting | 1 | 0 | 1 | 0 |
| Observation | Observed someone using bamboo / seen/heard about the AF | 2 | 2 | 0 | 0 |
| Wood shortage | Firewood problem, access to natural forest wood | 8 | 3 | 3 | 2 |
| marketing orientation | Selling of tree products, production of charcoal, marketing experience, market orientation | 4 | 2 | 2 | 0 |
| Land degradation | Land degradation perception, soil erosion, deforestation | 6 | 3 | 2 | 1 |

Table 4. Synthesis of some of the factors affecting AF adoption

| AF innovation category | Enabling factors | Constraining factors | References |
|---|---|---|---|
| Climate adaptation | secured tenure, sufficient credit & extension service, intensified campaigns on adaptation strategies | households difficulty to making costly decisions, agro-ecological specificity, information on climate scenarios | Akrofi-Atitianti et al 2018;Bryan et al 2013; Deressa et al 2009;Fagariba et al 2018 |
| Fodder | favorable attitude & biophysical conditions, regular training, farmer experimentation | lack of capital & technical knowledge, inaccessible market & quality seeds, agronomic problems | Katanga et al 2007;Kiyani et al 2017;Mekoya et al 2008;Nyaga et al 2015;Jera & Ajayi 2008 |
| Fertility management | expert training & supporting national extension, easy to integrate with current production | incompatibility to existing production, labor and land availability | Ajayi et al 2011; Nyaga et al 2015; Coulibaly et al 2017; Keil et al 2005; Kiptot et al 2008 |
| Fruit trees | good market prospects, easy management & resilience, tenure security | high operating costs, lack of knowledge on indigenous fruits trees cultivation, frost, pests | Iiyama et al 2018;Molua 2005;Nyaga et al 2015; German et al 2009; Nigussie et al 2018 |
| Mixed/multipurpose/alley | access to seeds/seedlings, population growth, scarcity of tree products, availability of market, incentives | agro-ecological & production system incompatibility, pests, theft, free grazing , lack of training and information | Appiah & Papinnen 2010; |
| Sustainable land management | awareness & positive attitudes on restoration, technical capacity | labor intensiveness, high opportunity cost of knowledge & technology | Etongo et al 2018; Nahayo et al 2016;Wafula et al 2015; Zeweld et al 2018 |
| Woodlot/timber/non-timber/ Cash | opportunity seekers who pursue profitability and property rights, high financial flow, sufficient land, incentives | investment cost, poor markets/profitability | Basinger et al 2011; Duguma 2012;Jerneck & Olsson 2014; Jenbere et al 2012 |

Table 5. Summary of non-econometric/ qualitative AF adoption studies

| Thematic area | Authors | Findings and suggestions |
|---|---|---|
| Innovation characteristics | Ajayi et al 2011; Bucagu et al 2013; Iiyama et al 2018 | • New and complex innovations are less adopted<br>• compatibility, resilience to climate risks, easiness of management are essential for adoption<br>• Tree utility (different benefits) is important character<br>• prioritize and adapt AF species that match farmer preferences or desired attributes<br>• Provide innovation options suiting to different households and agro-ecologies<br>• include innovations that generate income |

| | | |
|---|---|---|
| Extension | Ajayi et al 2011; Darr and Pretzsch 2008; Guteta & Abegaz 2015; Isaac et al 2007; Iiyama et al 2018; Oduro et al 2018 | • Farmer groups are most effective mechanisms of innovation diffusion<br>• No single most effective scaling up strategy rather mix of strategies<br>• Group approach is more effective than individual extension approach for innovation diffusion<br>• Farmers rely on both formal and informal information sources<br>• Participate farmers in the generation/adaptation process<br>• Promote community involvement and facilitate knowledge exchange<br>• Arrange education programs and capacity training<br>• Promotion should consider farmers multiple criteria , awareness & resource availability |
| Gender | Elias et al 2015; Shackleton et al 2007 | • Overlap of knowledge on uses, practices and preferences across gender among spouses<br>• Also existence of diverse needs among households is reported<br>• So, consider overlap and diversity of needs among households and the household itself<br>• Target women as well as they are influential in decision making process |
| Policy frameworks | Foundjem-Tita et al 2013; Appiah and Pappinen 2010; | • Mission statements of existing laws support AF expansion<br>• Actual legislation mostly contradicts by restricting transport of some wood products<br>• Revision of existing laws and regulations to address clarity issues<br>• Develop incentive mechanisms<br>• Policy on nurturing role of women |
| Profitability | Duguma 2012; Moloua 2005; Rahim et al 2017;Iiyama et al 2018 | • Profitability varies among AF systems<br>• Woodlots and boundary plantings farmland AF are most profitable followed by homesteads and<br>• Limited benefits (multipurpose) constrain adoption<br>• Extension contact is important for profitability |
| Institutions and support programs | Lilleso et al 2011;Johanssen et al 2013 | • Commercial, decentralized model holds most promise for sustainability of AF input supply<br>• Strong collaboration among stakeholders lead to better practice of AF by smallholders<br>• Renovate (redefine roles) institutions for more efficient AF input supply<br>• Create a collaborative platform among stakeholders for effective scaling up activities |
| Knowledge and incentives | Kiyani et al 2017; Oduro et al 2018; Chitakira et al 2010 | • AF adopters acquired increased income and environmental benefits compared to non-adopters<br>• limited skills, technical knowledge, capital & quality seeds drag adoption<br>• Provide grants, subsidies to farmers, farming inputs and establishing tree nurseries to |

| | | |
|---|---|---|
| Household attributes | Chitakira et al 2010;Oduro et al 2018; Appiah and Pappinen 2010; Ite 2005; Jerneck & Olsson 2013; Mekoya et al 2008;Iiyama et al 2018; Nyaga et al 2015 | • Farmers are aware of the benefits of trees<br>• Frequent mismatches between introduced innovations & farmers needs<br>• Most farmers prefer exotic tree with Immediate benefits<br>• Land scarcity constrain farmland AF adoption<br>• Focus only to biological & technical aspects disregards local interests and results in low adoption<br>• Farmers continuously adjust to and invest in their environment<br>• The better off 'opportunity seekers' readily adopt AF than the poor who are 'risk evaders'<br>• Recognize local farm priorities and constraints<br>• AF adoption must be understood within the wider socio-ecological system |
| Farmer experimentation and innovation | Katanga et al 2007;Iiyama et al 2018 | • Conventional research recommendations are not readily adopted by farmers despite incentives<br>• Farmers adapt and continuously create local knowledge<br>• farmers experiences and skills complements researchers knowledge<br>• Tree management & performance appear similar as farmers learn from each other<br>• Encourage farmers experimentation<br>• Characterize innovators and how the innovations can be best shared among farmers<br>• Promote continuing process of innovations than dissemination |
| Biophysical | Ajayi et al 2015; Bucagu et al 2013 | • Favorable environment such as homesteads led to higher survival rate<br>• Better tree productivity on contours<br>• Fruit trees got more management<br>• Locational flexibility is an important factor<br>• Farmers from different agro-ecologies have different preference |
| Risk, vulnerability and profitability | Chitakira et al 2010; Guteta & Abegaz 2015; Iiyama et al 2018; Sirrine et al 2010 | • Climate and pest related risks reduce adoption<br>• Damage by animals, frost, uncontrolled fire challenge adoption<br>• Presence of pests to crops may boost AF adoption<br>• Consider risk, profitability & vulnerability while recommending AF production system |
| Inputs | Chitakira et al 2010; Guteta & Abegaz 2015; Iiyama et al 2018 | • Shortage of inputs and high financial costs reduce adoption |
| Markets | Iiyama et al 2018 | • Guaranteed access to market is essential condition for sustainable adoption |

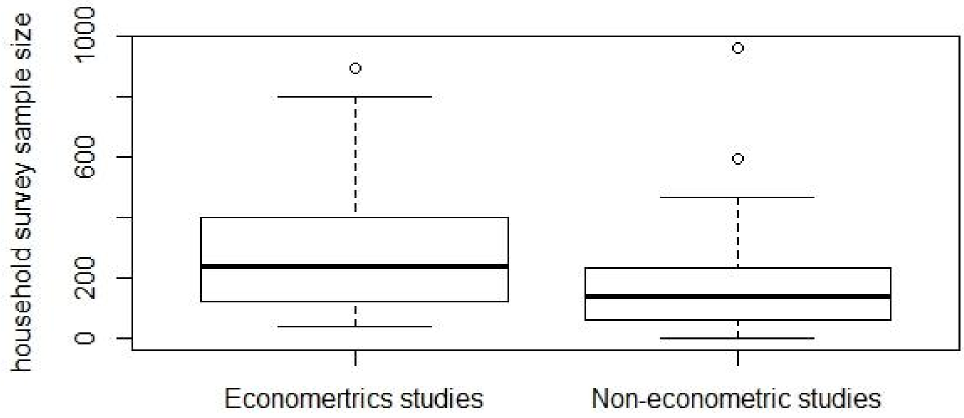


Figure-1. Sample size for household interview of reviewed AF studies

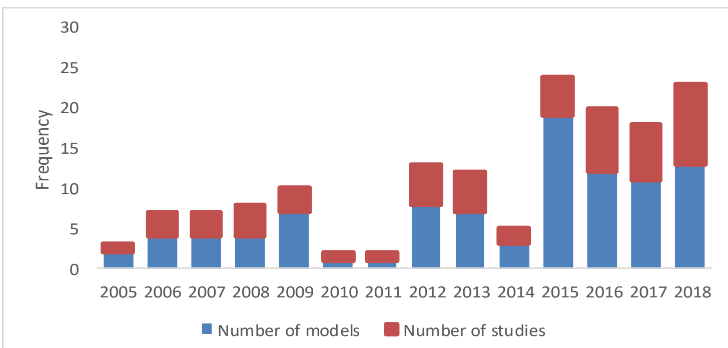


Figure -2 AF adoption econometric studies and models across years

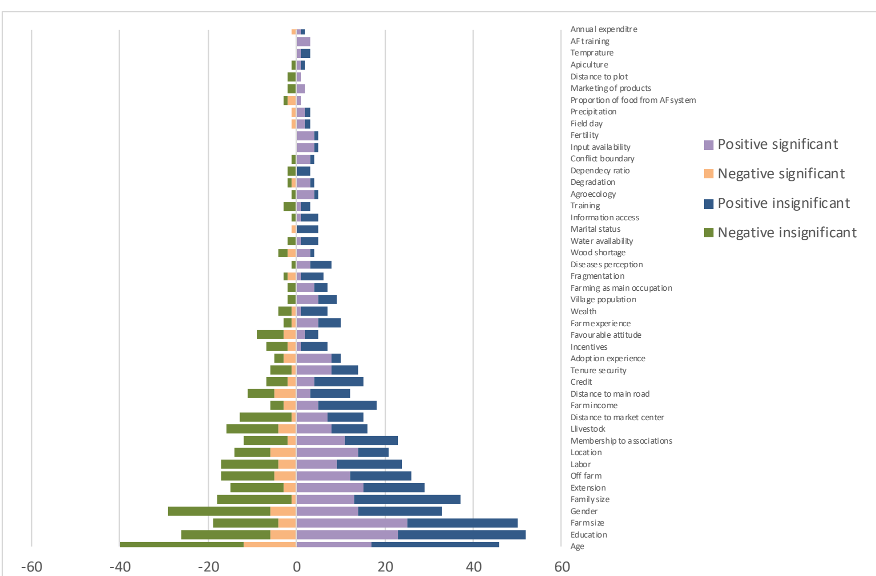


Figure-3 Forest plot of for 39 most common variables

## Table 6. List of AF species incorporated by the studies

| | | | | | |
|---|---|---|---|---|---|
| Acacia albida | Acacia abysinica | Acacia angustissima | Acacia auriculiformis | Acacia decurrens | Acacia galphinni |
| Acacia gerrardii | Acacia karoo | Acacia lahai | Acacia mearnsii | Acacia mellifera | Acacia nilotica |
| Acacia polyacantha | Acacia senegal | Acacia seyal | | Acacia Tephrosia | Acacia tortilis |
| Acacia xanthophloea | Adansonia digitata | Aframomum spp | Albizia amara | Albizia coriaria | Alnus acuminate |
| Aloe ferox | Aningeria robusta | Annona squamosa | Antiaris africana | Antrocaryon micraster | Artocarpus altilis |
| Artocarpus heterophyllus | | Azanza garckeana | Balanites aegyptiaca | Bambusa vulgaris | Berchemia discolor |
| Bombax costatum | Brachystegia spiciformis | Crotalaria grahamiana | Cupressus lusitanica | Cajanus cajan | Calliandra calothyrsus |
| | Callistemon citrinus | Callitris spp. | Calpurnia aurea | Carica papaya | Cascabela thevetia |
| Casimiroa edulis | Cassia abbreviata | | Casuarina equisetifolia | Cedrela odorata | Cedrela serrata |
| | Ceiba pentandra | Citrus aurantium | Citrus lemon | Citrus sinensis | Cocos nucifera |
| Coffea arabica | Combretum collinum | Combretum spp. | Commiphora africana | | Cordia africana |
| Cordial abyssinica | Crotolaria grahamiana | Crotolaria ochroleuca | Croton macrostachyus | Croton megalocarpus | Cupressus lusitanica |
| Dacryodes edulis | | Delonix elata | Detarium microcarpum | Diospyros dichrophylla | Diospyros mespiliformis |
| Dombeya rotundifolia | Elaeis gueneensis | Elaeodendron buchananii | Entandrophragma angolense | Eriobotrya japonica | Erythrina abyssinica |
| Erythrina caffra | Erythrina tomentosa | | Eucalyptus camaldulensis | Eucalyptus globulus | Eucalyptus urophyla |
| Euphorbia ingens | | Euphorbia tirrucalli | Faidherbia albida | Ficus capensis | |
| Ficus sycomorus | Ficus thonningii | Ficus vasta | Ficus robusta | Garcinia kola | Gliricidia sepium |
| Gmelina arborea | Gnetum africanum | Grevillea robusta | Grevillia sepium | Guarea thompsonii | Guizotia abyssinica |
| Heritiera utilis | Hevea brasiliensis | Irvingia gabonensis | | Jacaranda mimosifolia | |
| Jatropha curcas | Juniperus Procera | Khaya ivorensis | Kigelia africana | Lannea microcarpum | Leucaena leucocephala |
| Leucaena pallida | | Leuceana leucocephala | Lonchocarpus capassa | Lophira alata | Malus domestica |
| Mammea Africana | Mangifera indica | Mansonia altissima | Markhamia lutea | | Melia azedarach |
| Melia volkensii | Milicia excels | Milletia ferruginea | Moringa oleifera | | |
| Morrus alba | Mucuna Puriens | | Nauclea diderrichii | Olea capensis | Olea europaea |
| Opuntia ficus-indica | Parkia biglobosa | Persea americana | Piliostigma thonningii | Pinus patula | Podocarpus falcatus |
| Prosopis africana | Prunus africana | Prunus persicus | Psidium guajava | Pycnanthus angolensis | Rhaminus prinoides |
| Ricinodendron heudelotii | Rubus spp. | Salvadora persica | Sapium ellipticum | | Sclerocarya birrea |
| Scutia myrtina | Senna siamea | Senna spectabilis | Sesbania grandiflora | Sesbania sesban | |
| Solanecio mannii | Spathodea campanulata | Strychnos cocculoides | Syzygium guineense | Tamarindus indica | Tectona grandis |
| Tephrosia candida | Tephrosia vogelii | Terminalia catappa | Terminalia ivorensis | Terminalia prunioides | Terminalia superba |
| Theobroma cacao | Thevetia peruviana | Tieghemella heckelii | Tithonia diversifolia | Trichilia emetica | Trichilia emetica |
| Triplochiton scleroxylon | Turraeanthus africana | Uapaca kirkiana | Vernonia amygdalina | | Vitellaria paradoxa |
| Warbugia ugandensis | Ziziphus abyssinica | Zizyphus mucronata | Others unspecified | | |

Appendix B: Supplementary files of Chapter 4.2

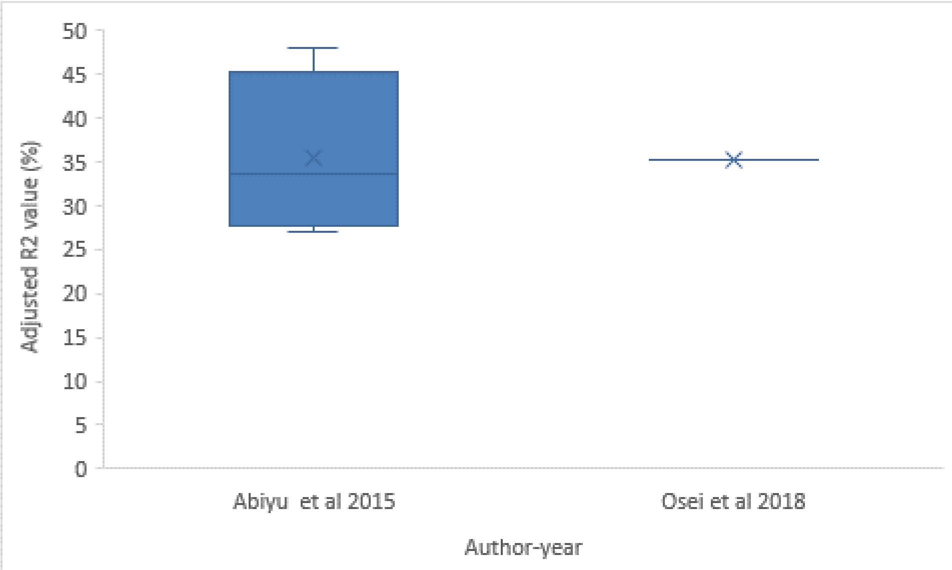


Figure 1. Farm level variables variance explanation power as revealed by adjusted $R^2$ of the model; Only those studies that implemented linear regression and inserted farm level variables in their model are considered for this analysis (source: Amare and Darr (2020).

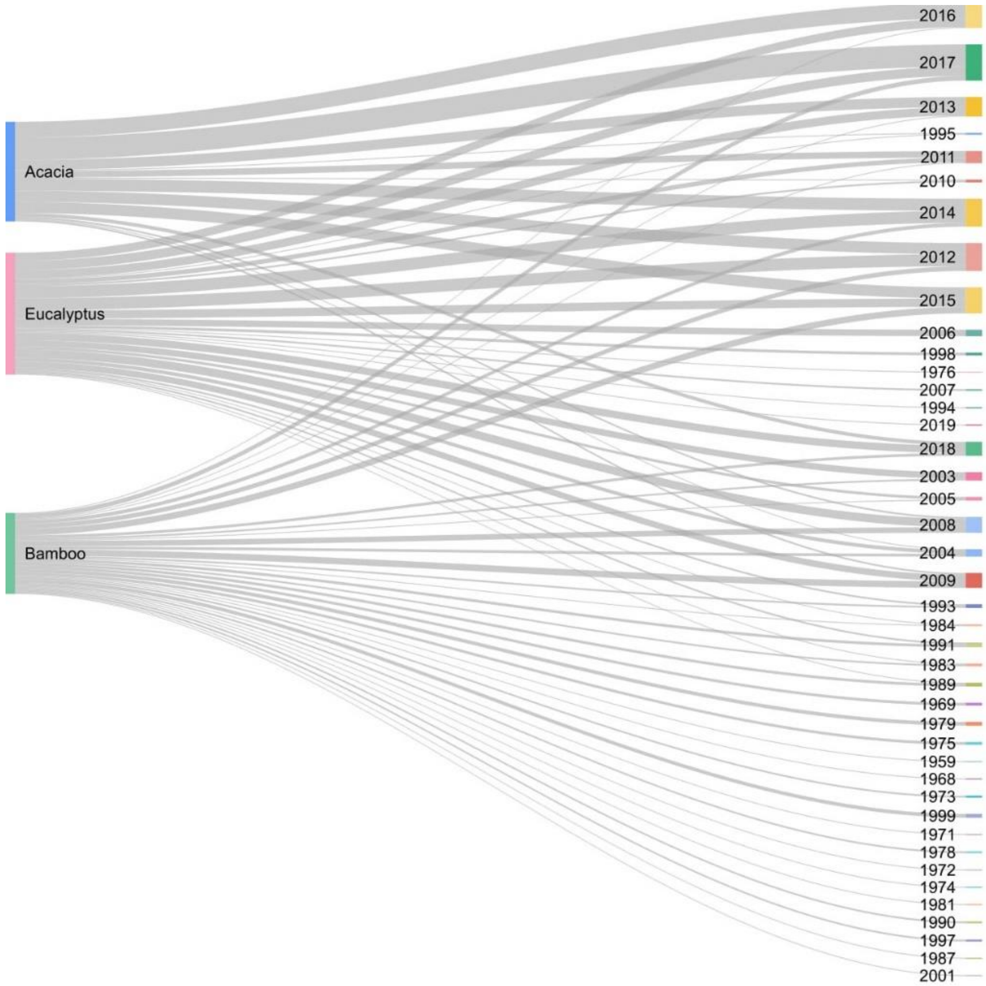


Figure 2.Sankey diagram showing adoption trend (numbers/nodes represent year of adoption and density of links represents number of adopters in that specific year)

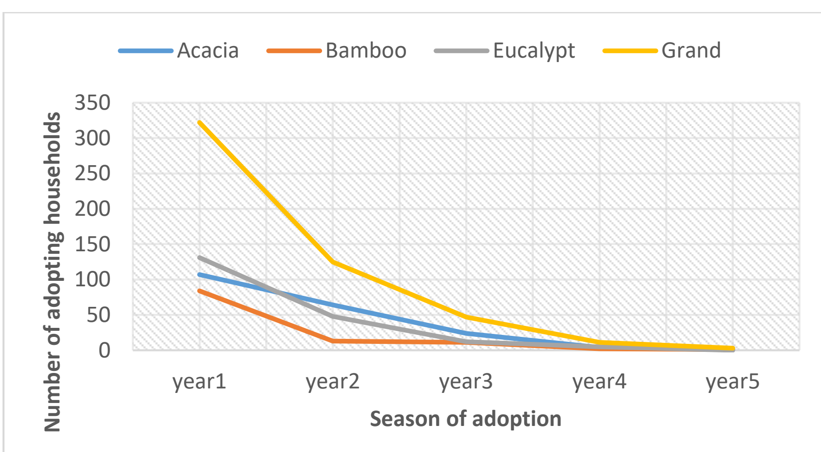


Figure 3. Number of adopters across years

Table 1. Cross-sectional multiple regression analysis

| | Coefficient | Std. Err. | t | P |
|---|---|---|---|---|
| Age | -.0169367 | .0273102 | -0.62 | 0.542 |
| Years of schooling | -.0282885 | .0417171 | -0.68 | 0.505 |
| Farm size | .2245453 | .0735463 | 3.05 | 0.006 |
| Family size | -.1652506 | .0856877 | -1.93 | 0.067 |
| Social capital index | -1.487321 | 1.090017 | -1.36 | 0.187 |
| Livestock in TLU | -.076962 | .0843201 | -0.91 | 0.372 |
| Farming income | .0000161 | 5.95e-06 | 2.71 | 0.013 |
| Non-farming income | 8.38e-06 | .0000314 | 0.27 | 0.792 |
| Consultation type | -.3371927 | .3120262 | -1.08 | 0.292 |
| Absolute type | .0225378 | .4311465 | 0.05 | 0.959 |
| Asset index | 1.248353 | .7960994 | 1.57 | 0.132 |
| Red soil type | -.1821636 | .4688884 | -0.39 | 0.702 |
| Farming experience | .0143359 | .0201131 | 0.71 | 0.484 |
| Constant | 2.342888 | 1.230811 | 1.90 | 0.071 |

Multiple regression analysis of a cross-sectional data (recent data compiled as 3rd season adoption is used for the analysis) as a comparison to the retrospective data analysis of Table 2. Number of obs = 35, F (13, 21)= 3.28, Prob > F = 0.0076, R-squared = 0.6699, Adj R-squared = 0.4655.

## Appendix C: Supplementary files of Chapter 4.3

Table 1. Multi-collinearity test for observed items

| Variable | VIF | Tolerance |
|---|---|---|
| ATT1 | 2.13 | 0.469037 |
| ATT2 | 1.97 | 0.507232 |
| INT1 | 2.24 | 0.447179 |
| INT2 | 2.43 | 0.411883 |
| INT3 | 1.97 | 0.508252 |
| PBC1 | 1.63 | 0.613141 |
| PBC2 | 1.57 | 0.635227 |
| SN1 | 1.53 | 0.652108 |
| SN2 | 1.70 | 0.587564 |
| Mean VIF | 1.91 | |

Table 2. questionnaire on salient items

| Item | Statement | Scale (1-5) | Construct category |
|---|---|---|---|
| INT1 | I intend to continue practicing this AF at least with current intensity | (1) strongly disagree- (5) strongly agree | Intention |
| INT2 | I plan to expand practicing of this AF to other plots | (1) strongly disagree- (5) strongly agree | Intention |
| INT3 | I am proposing to modify this AF practices to draw all benefits | (1) strongly disagree- (5) strongly agree | Intention |

| | | | |
|---|---|---|---|
| ATT1 | AF practice is central to my livelihood (e.g., source of cash income, energy) | (1) strongly disagree- (5) strongly agree | Attitude |
| ATT2 | The current AF is important to counter cash constraints and improve livelihoods | (1) strongly disagree- (5) strongly agree | Attitude |
| PBC1 | The land resources available make my engagement in AF readily | (1) strongly disagree- (5) strongly agree | Perceived behavioral control |
| PBC2 | I can easily engage in producing this AF (e.g., due to available skills) | (1) strongly disagree- (5) strongly agree | Perceived behavioral control |
| SN1 | Government and community wanted me to produce this AF only on marginal lands | (1) strongly disagree- (5) strongly agree | Subjective norms |
| SN2 | Local leaders and government officers would expect me to produce AF to improve my livelihoods** | (1) strongly disagree- (5) strongly agree | Subjective norms |

**Farmers were briefed the significant others as siblings, neighbors and experts as well as other people whom the farmers thought have influenced their behavior

Table 3. Descriptive summary of the items and their mean values

| Items | Agroforestry woodlot innovation | | | |
|---|---|---|---|---|
| | Bamboo (88) | Acacia (107) | Eucalyptus (132) | Combined (327) |
| INT1 | 3.93(0.14) | 3.95(0.12) | 3.07(0.13) | 3.59(0.08) |
| INT2 | 3.43(0.17) | 3.61(0.14) | 2.39(0.12) | 3.07(0.09) |
| INT3 | 3.19(0.16) | 3.05(0.15) | 2.27(0.12) | 2.77(0.08) |
| Intention (mean) | 3.52(0.14) | 3.54(0.12) | 2.57(0.1) | 3.14(0.07) |
| ATT1 | 3.64(0.13) | 3.92(0.1) | 3.49(0.1) | 3.67(0.06) |
| ATT2 | 3.63(0.13) | 4.07(0.09) | 3.57(0.09) | 3.75(0.06) |
| Attitude (mean) | 3.63(0.13) | 3.995(0.09) | 3.53(0.08) | 3.71(0.06) |
| SN1 | 2.56(0.15) | 3.68(0.14) | 2.45(0.1) | 2.88(0.08) |
| SN2 | 2.72(0.13) | 3.98(0.1) | 2.36(0.10) | 2.99(0.07) |
| Subjective Norm (mean) | 2.64(0.12) | 3.83(0.11) | 2.41(0.08) | 2.94(0.07) |
| PBC1 | 3.34(0.13) | 3.83(0.09) | 2.64(0.1) | 3.22(0.07) |
| PBC2 | 3.67(0.13) | 4.07(0.09) | 3.31(0.09) | 3.66(0.06) |
| Perceived behavioral control (mean) | 3.51(0.12) | 3.95(0.08) | 2.98(0.07) | 3.44(0.05) |

* All measurements are made in Likert values (refer Table 2); number represent mean Likert values while numbers in bracket are standard errors (±). The numbers beside agroforestry innovations refer the sample size from each agroforestry innovation whereas the combined refer the total.

Appendix D: Supplementary files of Chapter 4.4

*Table 1. Constructs and items used to illicit AF attributes*

| Variable/construct | Items | Value |
|---|---|---|
| Relative advantage by attribute | 1-6(1=very low to 6=extremely highly) | |
| | 1. This AF is more preferable/comfortable to produce than other available species | |
| | 2. This AF is more reliable than others | |
| | 3. This AF has wider adaptability (produced in more locations than others) | |
| | 4. This AF species has short duration or matures quickly | |
| | 5. This AF species matures uniformly | |
| | 6. This AF favours subsequent production | |
| | 7. This AF has more product options (fodder, fuelwood, charcoal, construction) compared to available options | |
| | 8. This AF can be harvested lifelong with low or no management | |
| | 9. This AF required no special (fertile, slope context) land requirement | |
| Relative advantage by economic advantage | 1-6(1=very low to 6=extremely highly) | |
| | 1. This AF requires low initial investment | |
| | 2. This AF saves adopters labor resources for management compared to crop production | |
| | 3. This AF requires more labour outside peak agricultural season | |
| | 4. This AF has an attractive price over its products compared to other AF species | |
| | 5. This AF helps to have cash flows during periods of short cash flow//offsets yearly cash restraints | |
| | 6. This AF brings large income at one time | |
| | 7. The products from this AF are better preferred by the market than available AF species | |
| Relative advantage by social advantage | 1-6(1=not at all to 6=extremely) | |
| | 1. It would be socially prestigious to produce this AF | |
| | 2. This AF has great social reward associated with its production | |
| | 3. Others will be impressed with my production of this AF (may be scenic value) | |
| Trialability (experimentation/customizability) | 1-6(1= not at all to 6= absolutely possible) | |
| | 1. This AF can be verified without planting | |
| | 2. This AF can be tried on small size) | |
| | 3. This AF can be customized based on adopters specifications (mgmt.,size and year of plantation) | |
| | 4. This AF provides unique features specified by the adopter or buyers (like charcoal quality) | |
| Observability (and communicability) | 1-6(1= not observable at all to 6= extremely) | |
| | 1. Others can observe how to establish this AF | |
| | 2. Others can observe the performance of this AF | |
| | 3. Others can observe any problems this AF causes | |
| | 4. It is common to see this AF produced by others | |
| | 5. It would be easy to describe this AF to others | |
| Compatibility Personal | 1-5(1= not compatible at all to 6= extremely) | |
| | 1. This AF does not compete with other production (for sunlight, nutrients) systems | |
| | 2. Producing this AF compliments other produces currently produced by the farmer | |
| | 3. This AF fits into the adopters livelihood strategy | |
| | 4. This AF helps to keep the farmers self-image | |
| | 5. This AF is compatible with climate and edaphic characteristics | |
| | 6. This AF is compatible to my level of knowledge and skill | |
| | 7. This AF is compatible to the values and norms I adhere | |
| | 8. This AF is compatible to resources (e.g., labor, land) available at my household | |
| Social Compatibility | 1-6(1= not compatibility at all to 6= extremely) | |
| | 1. Producing this AF is socially acceptable | |
| | 2. Adopting this AF would be met with approval by neighbours/bordering farmers and family | |
| | 3. Many of my neighbours/friends would want me to produce this AF | |

| Volition | 1-6(1= not at all to 6=extremely voluntary) | |
|---|---|---|
| | 1. My neighbours encouraged at times forced me to produce this AF | |
| | 2. The bordering plots being planted forced me to plant this AF due to shade effect | |
| **Performance** | **1-6(1=v. low to 6=extremely high)** | |
| | 1. This AF is vigorous (high survival rate, withstands mgmt., low mortality) | |
| | 2. This AF will perform reliably and consistently | |
| | 3. I am confident that this AF will perform as I expected | |
| | 4. The products from this AF meets customers satisfaction | |
| | 5. This AF is most resource efficient (investment vs. yield) | |
| | 6. This AF provides one of the best ecological services (e.g., fertility increment) | |
| | 7. This AF aligns with the values, culture and is consistent with the households life goals | |
| **Complexity in mgmt. & utilization/harvesting; 1-6(1= not complex at all to 6=extremely complex)** | | |
| | 1. This AF takes a considerable task to perform | |
| | 2. This AF requires complex (large) tools and equipment to manage and process | |
| | 3. This AF requires complex harvesting techniques | |
| | 4. This AF requires high end (complex) marketing strategy | |
| | 5. This AF requires higher level of general knowledge to produce | |
| | 6. This AF requires new skills and collaboration with researchers, value chain actors for productivity | |
| | 7. Special management skills and knowledge are required to produce this AF | |
| | 8. This AF is technically complex to plant and manage | |
| **Risk category** | **1-6(1=no risk at all to 6= completely)** | |
| | 1. Products from this AF have negative health effects | |
| | 2. This AF has a higher risk to land stabilization | |
| | 3. This AF has higher degradation risks to land | |
| | 4. This AF is drought resistant and performs well | |
| | 5. This AF is diseases and flood resistant | |
| | 6. This AF performs in pouring rainfall conditions | |
| **Discontinuity** | **1-6(1=not at all to 6= completely)** | |
| | 1. This AF is new to the area | |
| | 2. This AF provides radically new product options or features and benefits than the existing ones | |
| | 3. This AF can be uprooted/dis-invested easily when there is necessity | |

*** The table compiles the items for the nine constructs. Yet tit shows 12 constructs as the relative advantage and compatibility constructs are disintegrated for easiness of visualizing. Hence, the first three attributes namely relative advantage by attribute, relative attribute by economic advantage and relative advantage by social advantage are components of the relative advantage construct; compatibility personal and compatibility social constitute the compatibility attribute.

Table 2. Reliability test

| Construct | Cronbach alpha (α) | | | |
|---|---|---|---|---|
| | Acacia (88) | Bamboo (107) | Eucalyptus (132) | Combined (327) |
| Relative advantage | 0.6957 | 0.7569 | 0.8091 | 0.7767 |
| Compatibility | 0.7228 | 0.8300 | 0.7656 | 0.7987 |
| Complexity | 0.8204 | 0.7940 | 0.8585 | 0.8189 |
| Observability | 0.9241 | 0.9228 | 0.9182 | 0.9178 |
| Trialability | 0.5763 | 0.3412 | 0.7119 | 0.5552 |
| Discontinuity | 0.5490 | 0.4051 | 0.2787 | 0.5263 |
| Performance | 0.7532 | 0.7338 | 0.5883 | 0.7333 |
| Risk | 0.5815 | 0.5963 | 0.7307 | 0.5726 |
| Volition | 0.7495 | 0.7130 | 0.6274 | 0.6539 |

*numbers in bracket are sample sizes

Table 3.Eigen values of orthogonal varimax rotated correlation matrix

| Component | Eigenvalue | Variance | Difference | Proportion | Cumulative |
|---|---|---|---|---|---|
| Comp1 | 10.7163 | 5.74704 | 1.65628 | 0.1149 | 0.1149 |
| Comp2 | 5.14755 | 4.09076 | 0.491608 | 0.0818 | 0.1968 |
| Comp3 | 3.98225 | 3.59915 | 0.459664 | 0.0720 | 0.2687 |
| Comp4 | 3.75199 | 3.13949 | 0.223536 | 0.0628 | 0.3315 |
| Comp5 | 2.32095 | 2.91595 | 0.0149145 | 0.0583 | 0.3898 |
| Comp6 | 2.09851 | 2.90104 | 0.351837 | 0.0580 | 0.4479 |
| Comp7 | 1.63163 | 2.5492 | 0.0149685 | 0.0510 | 0.4989 |
| Comp8 | 1.40641 | 2.53423 | 0.010169 | 0.0507 | 0.5495 |
| Comp9 | 1.29174 | 2.52406 | 0.208017 | 0.0505 | 0.6000 |
| Comp10 | 1.23886 | 2.31605 | 0.531097 | 0.0463 | 0.6463 |
| Comp11 | 1.17855 | 1.78495 | 0.0960649 | 0.0357 | 0.6820 |
| Comp12 | 1.02608 | 1.68888 | . | 0.0338 | 0.7158 |

Principal components/correlation; Number of obs= 145; Number of components =12; Trace =50; Rotation: orthogonal varimax (Kaiser off) Rho = 0.7158. The 2nd column is provided as a reference to PCA Eigen value before rotation and to that after rotation (3rd column).

Table 4. PCA of rotated components

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 | PC13 | PC14 | PC15 | PC16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Preferable | 0.0208 | -0.0028 | 0.0246 | -0.0787 | 0.5716 | -0.0149 | -0.0533 | -0.0515 | 0.0066 | 0.0596 | 0.0658 | 0.0159 | 0.0756 | -0.0116 | -0.0172 | 0.0634 |
| Reliable | -0.0549 | 0.0165 | -0.0813 | 0.0211 | 0.5422 | 0.0498 | 0.0376 | -0.0770 | 0.0813 | -0.0113 | 0.0554 | -0.0260 | -0.0706 | 0.0640 | 0.0334 | 0.0589 |
| Aaptability | -0.0169 | 0.0844 | 0.4037 | 0.1203 | -0.0654 | 0.0751 | 0.1040 | -0.0677 | 0.0051 | 0.1438 | 0.0796 | -0.2596 | -0.2119 | 0.0630 | 0.1271 | -0.0501 |
| Mature | 0.0081 | 0.0288 | 0.0515 | -0.0700 | 0.0832 | 0.0388 | -0.0621 | 0.0859 | 0.5948 | 0.1045 | -0.0367 | 0.0749 | 0.1216 | 0.0037 | 0.0073 | -0.0231 |
| Uniform | 0.0852 | -0.0122 | 0.4466 | -0.0523 | 0.0265 | 0.0063 | -0.0034 | 0.0095 | 0.1208 | -0.0099 | -0.1602 | 0.0844 | 0.1402 | -0.1002 | 0.0451 | 0.0880 |
| Favor | -0.0708 | -0.0183 | -0.0127 | 0.1122 | 0.0345 | -0.0074 | 0.0589 | -0.0482 | 0.1196 | -0.0124 | -0.0074 | 0.5155 | -0.1297 | 0.0285 | 0.0699 | 0.0114 |
| Options | -0.0057 | -0.0359 | -0.0304 | 0.0283 | 0.0147 | 0.0330 | 0.1653 | 0.0176 | 0.0448 | 0.6206 | -0.1190 | 0.0168 | -0.0032 | 0.0509 | -0.0618 | -0.0715 |
| Lifelong | 0.0193 | 0.0803 | -0.4063 | 0.0359 | 0.1046 | -0.1081 | 0.0342 | 0.0187 | 0.0583 | 0.1206 | -0.1505 | -0.0299 | 0.0210 | 0.1432 | 0.0901 | -0.0030 |
| Requires | 0.0751 | 0.1506 | -0.1384 | 0.0733 | -0.0631 | 0.1250 | -0.0544 | 0.1828 | 0.1644 | -0.0349 | -0.1737 | 0.0277 | 0.0215 | -0.2233 | 0.4764 | 0.2339 |
| Investment | 0.0652 | 0.0225 | -0.0571 | -0.0509 | 0.1368 | 0.2602 | 0.1494 | 0.0678 | 0.0577 | -0.0822 | 0.0093 | -0.3298 | -0.0610 | 0.1037 | 0.1068 | 0.1557 |
| Labor | -0.0206 | -0.0545 | 0.0437 | -0.0504 | 0.0287 | -0.0154 | 0.0361 | -0.0860 | -0.0355 | -0.0185 | 0.0301 | 0.0042 | 0.0009 | 0.0282 | 0.7279 | -0.1027 |
| Peak | 0.0087 | -0.0385 | 0.0155 | 0.0272 | 0.0690 | -0.0231 | 0.0609 | -0.0184 | -0.0161 | -0.0607 | -0.0480 | 0.0032 | -0.0213 | -0.0220 | -0.0625 | 0.7235 |
| AttractiveP | 0.0369 | 0.0983 | 0.1194 | -0.0989 | 0.2521 | -0.1047 | -0.0153 | 0.2046 | -0.2847 | 0.1227 | -0.0123 | 0.2715 | -0.0417 | 0.0174 | 0.0514 | 0.0352 |
| CashFlow | 0.0566 | 0.0677 | 0.1390 | 0.0266 | 0.0586 | -0.0241 | -0.1393 | 0.0899 | 0.0419 | 0.4375 | 0.2785 | -0.0040 | 0.0486 | -0.0895 | -0.0082 | 0.0198 |
| LargeIncome | -0.0533 | 0.0268 | 0.3434 | -0.0149 | 0.0807 | 0.1644 | -0.0375 | 0.0559 | -0.3413 | 0.0497 | -0.1961 | 0.0181 | 0.0336 | 0.0082 | -0.0448 | 0.0431 |
| Preffered | -0.0333 | -0.0586 | 0.1188 | 0.0119 | 0.2249 | -0.0987 | -0.0691 | 0.3362 | -0.1897 | -0.1734 | -0.1313 | 0.0453 | 0.0523 | 0.0493 | 0.1242 | -0.1051 |
| Prestigeous | 0.2165 | 0.0189 | -0.0636 | 0.3054 | 0.0527 | 0.0081 | 0.1702 | 0.0237 | -0.1339 | 0.0262 | 0.0130 | 0.1184 | -0.0318 | -0.1873 | -0.0332 | 0.0220 |
| Reward | -0.0660 | -0.0207 | 0.0088 | -0.0126 | -0.0159 | -0.0088 | 0.6378 | -0.0118 | -0.0155 | 0.0916 | 0.0451 | -0.0232 | 0.0393 | 0.0188 | 0.0170 | 0.0907 |
| Impressed | 0.1469 | 0.0661 | -0.0150 | 0.1268 | 0.0069 | -0.1065 | 0.3951 | 0.0243 | -0.1348 | 0.0299 | -0.0143 | 0.0883 | 0.1599 | -0.0342 | 0.0543 | -0.0363 |
| OEstablsih | 0.3957 | -0.0211 | -0.0002 | 0.0157 | -0.0280 | -0.0240 | -0.0252 | -0.0191 | -0.0137 | 0.0510 | 0.0858 | -0.0343 | -0.0364 | -0.0053 | -0.0455 | 0.0513 |
| OPerformance | 0.4196 | -0.0417 | 0.0223 | -0.0054 | -0.0201 | -0.0693 | -0.0675 | -0.0615 | 0.0144 | -0.0027 | 0.0253 | -0.0633 | -0.0143 | 0.0508 | 0.0019 | -0.0153 |
| OProblems | 0.4015 | -0.0030 | 0.0219 | -0.0369 | -0.0160 | 0.0224 | -0.0880 | -0.0284 | 0.0638 | 0.0166 | -0.0080 | -0.0717 | -0.0448 | 0.0127 | 0.0009 | 0.0357 |
| OCommon | 0.4047 | 0.0223 | -0.0056 | -0.0168 | -0.0011 | -0.0579 | -0.0459 | 0.0103 | 0.0148 | 0.0504 | 0.0195 | -0.0398 | -0.1534 | 0.0787 | 0.0202 | 0.0310 |
| Communicate | -0.0174 | -0.0145 | -0.0175 | -0.0506 | -0.0915 | 0.0268 | 0.0066 | 0.6373 | 0.0579 | 0.0510 | 0.0066 | -0.0337 | -0.0972 | 0.0410 | -0.0789 | -0.0223 |
| Vigorous | -0.0479 | 0.0507 | 0.1479 | -0.0102 | -0.0173 | 0.5395 | 0.0126 | 0.0304 | -0.0099 | 0.0613 | 0.0423 | -0.1145 | -0.1757 | -0.0429 | 0.0841 | -0.0400 |
| Consistent | -0.0269 | -0.0914 | -0.0214 | 0.0817 | 0.0294 | 0.4586 | -0.1015 | -0.0564 | 0.0417 | -0.0505 | 0.0584 | 0.0589 | 0.2506 | 0.0665 | -0.0529 | -0.0771 |
| Expected | 0.0632 | -0.0846 | -0.0817 | 0.1339 | 0.0618 | 0.2961 | -0.0689 | 0.0129 | 0.0832 | 0.0310 | -0.0537 | 0.1370 | 0.1483 | 0.1305 | -0.0372 | 0.0261 |
| Satisfaction | 0.0692 | -0.0107 | -0.0037 | -0.0192 | 0.0714 | -0.0113 | 0.0643 | 0.0107 | 0.0394 | 0.0112 | -0.1247 | -0.0297 | -0.0871 | 0.6239 | -0.0767 | -0.0445 |
| Efficient | -0.0528 | 0.0482 | -0.1641 | 0.0838 | -0.0900 | 0.0909 | -0.1437 | 0.2069 | -0.1304 | 0.0065 | 0.1847 | 0.0923 | 0.1162 | 0.4266 | 0.1196 | 0.0559 |
| Ecological | -0.0452 | -0.0082 | 0.2277 | -0.1240 | -0.1028 | 0.0600 | 0.2260 | -0.0213 | 0.0397 | -0.0493 | 0.1233 | 0.1989 | 0.0200 | 0.1973 | -0.0404 | -0.0549 |
| Task | 0.0313 | 0.0922 | 0.0403 | -0.0319 | -0.0422 | 0.0531 | 0.0564 | 0.1351 | -0.0380 | -0.3332 | 0.2183 | 0.0417 | 0.0607 | -0.0184 | -0.1584 | 0.1991 |
| Tools | 0.1026 | 0.2677 | -0.0267 | 0.0459 | -0.1504 | 0.1693 | -0.0749 | -0.1199 | -0.1109 | 0.0117 | -0.0051 | 0.1810 | 0.0800 | 0.1798 | 0.0005 | 0.0920 |
| Techniques | -0.0211 | 0.4404 | -0.0457 | -0.1163 | -0.0564 | -0.0271 | 0.0175 | 0.1060 | 0.0373 | 0.1251 | 0.2370 | 0.2220 | 0.0054 | -0.0279 | 0.0534 | -0.0714 |
| Marketing | -0.0532 | 0.0191 | 0.0330 | 0.0062 | 0.0031 | -0.0273 | 0.0938 | -0.1074 | 0.1135 | -0.0072 | 0.0350 | -0.0521 | 0.6372 | -0.0341 | 0.0190 | -0.0165 |
| Knowledge | -0.0575 | 0.3827 | -0.0340 | 0.0034 | -0.0237 | 0.0246 | 0.1258 | 0.0499 | -0.0525 | -0.0550 | 0.0457 | -0.0591 | 0.0414 | -0.0416 | 0.0425 | 0.0878 |
| Skills | -0.0381 | 0.3807 | -0.0033 | -0.0746 | 0.1001 | 0.0215 | 0.0903 | -0.0249 | 0.1420 | 0.0298 | -0.1321 | -0.1544 | 0.0025 | 0.0486 | -0.1999 | 0.1306 |
| Managment | -0.0324 | 0.4310 | 0.0421 | 0.1154 | 0.0197 | 0.0333 | -0.0924 | -0.1235 | 0.0287 | -0.1229 | -0.1280 | -0.0672 | -0.0609 | 0.0019 | -0.0638 | -0.1654 |
| Complex | 0.0656 | 0.3879 | 0.0570 | 0.0342 | 0.0774 | -0.1380 | -0.1058 | -0.0662 | -0.0743 | -0.0859 | -0.0706 | -0.0512 | 0.0534 | 0.0027 | -0.0045 | -0.1579 |
| Compete | -0.0934 | -0.0202 | 0.0775 | -0.0439 | 0.0305 | -0.0036 | 0.1347 | -0.0586 | 0.2039 | -0.1918 | -0.0528 | 0.1662 | -0.3104 | 0.1169 | -0.0053 | -0.0244 |
| Compliments | 0.0284 | 0.0277 | 0.0783 | 0.1024 | -0.0105 | -0.0401 | -0.0125 | -0.1456 | 0.2359 | -0.0648 | 0.1114 | 0.2828 | -0.2774 | -0.0294 | 0.0167 | 0.0618 |
| Fits | -0.0083 | -0.0099 | 0.0818 | 0.2782 | 0.1991 | 0.0120 | -0.1411 | -0.1599 | -0.1152 | 0.0270 | 0.2087 | 0.0028 | -0.0228 | 0.0790 | 0.0540 | 0.0660 |
| Selfimage | -0.0168 | -0.0035 | -0.0196 | 0.5951 | -0.0737 | 0.0819 | -0.0099 | -0.0727 | -0.0587 | 0.0630 | -0.1177 | 0.0969 | 0.0167 | -0.0272 | -0.0664 | 0.0220 |
| CClimatic | 0.0338 | 0.0010 | 0.2997 | 0.0860 | -0.0075 | -0.1451 | -0.0751 | 0.1088 | 0.1771 | - 0.0399 | -0.1089 | 0.0996 | 0.1915 | 0.1586 | -0.0116 | 0.0694 |
| CResources | -0.0516 | -0.0130 | 0.0803 | 0.3107 | 0.0924 | -0.2208 | 0.1089 | -0.0133 | 0.1226 | -0.1666 | 0.0549 | -0.2307 | 0.0340 | 0.1420 | 0.0762 | -0.1871 |
| CKSKILL | -0.0925 | -0.0150 | 0.0391 | 0.3619 | -0.0639 | -0.1103 | 0.0170 | 0.2553 | 0.0714 | -0.0034 | 0.1408 | -0.1353 | -0.0315 | 0.0890 | 0.0142 | 0.1134 |
| CNorms | 0.0702 | -0.0015 | 0.1100 | 0.1879 | 0.0355 | -0.0710 | -0.0441 | 0.2342 | 0.1970 | -0.0588 | 0.1090 | -0.0834 | 0.0327 | -0.1139 | -0.0549 | -0.0631 |
| Social | 0.0888 | -0.0068 | -0.1201 | 0.1015 | 0.2185 | 0.2364 | 0.1605 | 0.1938 | 0.0338 | -0.1328 | -0.1226 | 0.0784 | -0.1011 | -0.2512 | -0.1638 | -0.3095 |
| Approval | 0.2389 | 0.0370 | 0.0062 | -0.0344 | -0.0397 | 0.1083 | 0.1626 | 0.0085 | 0.0300 | -0.0971 | -0.0047 | -0.0000 | 0.0214 | 0.1045 | 0.0832 | -0.0821 |
| Want | 0.3157 | -0.0575 | 0.0384 | -0.0874 | 0.0139 | 0.0569 | 0.1414 | 0.0306 | -0.0351 | -0.1455 | -0.0469 | 0.1186 | 0.1690 | 0.0290 | 0.0059 | -0.1161 |
| Aligns | 0.0240 | -0.0203 | -0.0344 | -0.0544 | 0.0835 | 0.0417 | 0.0556 | -0.0128 | -0.0005 | -0.0766 | 0.6239 | -0.0068 | 0.0251 | -0.0553 | -0.0187 | -0.0675 |

## Appendix E: Supplementary files of Chapter 4.7

Table 1. CPT of artificial nodes

| Artificial nodes | Status (% of likelihood) | | References |
|---|---|---|---|
| Socioeconomic | No | Yes | Amare et al 2019; Abiyu et al 2016; Amare and Darr 2020; |
| | 50 | 50 | |
| | 43 | 57 | |
| | 33 | 67 | |
| | 30 | 70 | |
| Psychological | 50 | 50 | Ajzen 2011; Armitage and Connor 2001;Meijer et al (2015); Amare and Darr forthcoming; |
| | 52 | 48 | |
| | 54 | 46 | |
| Household contexts | 77 | 23 | Amare and Darr 2020;Pattanyak et al (2003);Mercer (2004);Motaubault and Avalavapati (2005) |
| | 70 | 30 | |
| | 68 | 32 | |
| | 67 | 33 | |
| | 65 | 35 | |
| | 60 | 40 | |
| | 50 | 50 | |
| | 40 | 60 | |
| System level features | 50 | 50 | Amare and Darr 2020; |
| | 56 | 44 | |
| | 74 | 26 | |
| Innovation attributes | 48 | 52 | Rogers 2003; Oca Minguai et al (2020); Amare and Darr forthcoming |
| | 52 | 48 | |
| | 54 | 46 | |
| | 50 | 50 | |

## Appendix F: Household Questionnaire

I. LOCATION OF THE HOUSEHOLD

Zone:____________Woreda:._____________Kebele:_______________Village:_____________ Type of AF:__________________________ Main agro-ecology and soil characteristics:_______
_______________________________________________________________________________

II. Household demography

Respondent's name: …………………………… Sex:______________

Age (years):____ Marital status:________ Education:____________

Family members (numbers):

Male; 0-14…………15-30yrs ………31-45yrs ………… 46-60yrs …………..> 60 yrs ………

Female; 0-14…………15-30yrs ………31-45yrs ………… 46-60yrs …………..> 60 yrs …………..

III. ACCESS TO SERVICE CENTERS

| Distance from home to | Distance (minutes/hour of walking) |
|---|---|
| Kebele administrative office | |
| Woreda town | |
| The nearest market center | |
| The main road | |

IV. HOUSEHOLD ASSETS

| Asset | Own (No, Yes) | Main importance |
|---|---|---|
| TV | | |
| Radio | | |
| Mobile phone | | |
| Cart | | |
| Bajaji | | |
| Solar panels | | |
| | | |
| Housing* Metal | number | |

V. LAND RESOURCES AND PLOT CHARACTERISTICS

1. How long have you been in farming or agriculture (years)?________________________
2. What is the size of land owned in the 2010/11 cropping season (in timad)
   a. Owned__________ c. Shared-in_______________ d. Shared –out___________
   b. Rented-in_______ e. Rented –out_______________

VI. LIVESTOCK OWNERSHIP

1. Please list down the type of livestock owned

| Type | Oxen | Cow | Calf | Goat | Sheep | Mule | Donkey | Horse |
|---|---|---|---|---|---|---|---|---|
| Number | | | | | | | | |

VII. AGROFORESTRY PRACTICES

1. What Major trees/shrubs you grow on your lands?

| Plantation site | Tree/shrub species | Coverage(counts) | Status (stage and pattern) | Crops produced | Other purposes |
|---|---|---|---|---|---|
| Crop land/agroforestry | | | | | |
| Homestead | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Grazing land (private) | | | | | |
| Farm forestry / Woodlots | | | | | |
| SWC structures | | | | | |
| Fencing/border | | | | | |

2. What are the major purposes of planting and managing trees? 0. for NRM 1. Food security 3. Risk averse 4. Lack of labor 5. Profits (better benefits) 6. Any other, please list ___________________________________________________________________________
3. Where do you get seedlings? 0. Own production 1. From neighbors producing seedlings 2. From government nursery 3. From BOA 4. NGOs (__________________) 5. Any other

VIII. AGROFORESTRY PRODUCTION (2010 E.C.)

1. Could you please specify the possible production system for the past 5 years of the current AF planted plot

| Season of production | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| Soil type | | | | | |
| Size of plot (timad/kada) | | | | | |
| Crop planted in combination with the AF | | | | | |
| Material inputs | | | | | |
| Precursor crop | | | | | |
| Seed(kg) | | | | | |
| Cost of seed (ETB) | | | | | |
| Seedling (no) | | | | | |
| Cost of seedling (ETB) | | | | | |
| Fertilizer (1.Yes 2. No) | | | | | |
| If yes, amount of - DAP(kg) | | | | | |
| -UREA(Kg) | | | | | |
| Cost of fertilizer - DAP | | | | | |
| - UREA | | | | | |
| Compost (0. No 1.Yes) | | | | | |
| If Yes, Amount(qt) | | | | | |
| Amount of labor (MD) | | | | | |
| Manure (0. No 1.Yes) | | | | | |
| If Yes, Amount(qt) | | | | | |
| Amount of labor (MD) | | | | | |
| Pesticides (lit) | | | | | |
| Cost of Pesticides | | | | | |
| Labor inputs | | | | | |
| Land preparation(days) | | | | | |
| Planting (number of days) | | | | | |
| Fertilization | | | | | |
| Manuring (MD) | | | | | |
| Weeding (MD) | | | | | |
| Spraying (MD) | | | | | |
| Maintenance (MD) | | | | | |
| Harvesting (MD) | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Transport (days) | | | | | |
| Output | | | | | |
| Yield of crop (qt or other metric) | | | | | |
| By-products (qt or other metric)<br>Product name: | | | | | |
| Amount crop sold (qt or other metric) | | | | | |
| Price of yield (Birr/ qt) | | | | | |
| Yield of tree (metric) | | | | | |
| By product from tree<br>Name: | | | | | |
| Total income from the production system | | | | | |

## IX. FARMER EXPERIENCE AND EXPERIMENTATION OR ADOPTION & DIS-ADOPTION

1. How long did you practice this AF from the first introduction?____________________________
2. What was the first package or scale of the AF during introduction? __________________________________
3. Who provided you this AF package? 0. Market 1. DAs 2. Cooperatives 3. Research center 4. NGOs
   __________________________________________________________
4. Do you intercrop AF? 0. NO 1. Yes.
5. If yes what was the major purpose of intercropping? 0) seed production 1) risk averse 2) disease protection 3) to optimize the seed quality as needed by the market 4) optimal land use 5. others_____________________
6. If you continued to use improved AF species after the first adoption, please can you list down them chronologically for the past 5 seasons? (do not consider it in consecutive years rather there could be years of gap between each)

| Parameters | | Year of adoption (Ethiopian Calendar) | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| AF species | | | | | | |
| Source[1] | | | | | | |
| First introduction mode[2] | | | | | | |
| Means of transfer[3] | | | | | | |
| Seedling (number) | | | | | | |
| Land size (timad) | | | | | | |
| Recommended management (type and intensity) | | | | | | |
| Modification introduced[4] | | | | | | |
| Org. involved in modification[5] | | | | | | |
| Role of org.[6] | | | | | | |
| Yield | Charcoal | | | | | |
| | Logs | | | | | |
| Income | Charcoal | | | | | |
| | Logs | | | | | |
| Reason if abandoned | | | | | | |

[1]0. Market 2. DAs 3. Cooperatives 4. Research center 5. NGOs; [2]demonstration, skills training, campaigns, others;[3] subsidized seedling delivery, free seedlings, intensive monitoring, nothing; [4]planting pattern or density (less or more plants per ha), combination with agricultural crops (explain which one), management practice (weeding frequency, hoeing frequency, fertilization, harvesting date); [5]org (extension agent, NGO),

role (support in knowledge, support in skill); [6] skills and knowledge update, monitoring, seed delivery, market information, others.

## X. INNOVATION CHARACTERISTICS

1. What were the first characteristics that attracted you to adopt/try the AF innovation?
____________________________________________________________________________________
_____________________________________________________________________________

2. Please rate the following items from low to high (1 to 6) (Please refer Appendix D Table 1)

## XI. PERCEPTIONS AND ATTITUDES (INCLUDING NON-MARKETABLE BENEFITS)

| Constructs and items | Likert |
|---|---|
| 1=Strongly disagree, 2= Disagree, 3= medium/neutral, 4= Agree, 5= Strongly agree | |
| Intentions | |
| I intend to continue practicing this AF | |
| I plan to expand practicing of this AF to other plots | |
| I am proposing to modify this AF practices to draw all benefits (ecological, economic, social and environmental) | |
| Attitude | |
| AF practice is central to my livelihood (e.g., source of cash income, energy) | |
| The current AF is important to counter cash constraints and improve livelihoods | |
| This AF supports and subsidizes other productions (e.g., livestock, crop) | |
| AF is beneficial to keep ecological benefits (e.g., improved soil fertility) | |
| AF is crucial for environmental benefits (e.g., aquifer management, wind break, and manage microclimate, rainfall and temperature) | |
| The current AF is the best enterprise option for the existing land condition (fertility, slope) | |
| This AF requires a lot of work to perform than engaging in crop activities | |
| This AF negatively influences food production ( e.g., root system, allelopathy, residuals) | |
| AF provides inputs to agricultural operations (e.g., implement) | |
| AF has negative environmental consequences (land degradation, soil erosion, huge water consumption) | |
| AF is creates habitat for damaging pests (make it only for beneficial pests and avoid repetition) | |
| AF creates conflict among bordering farmers | |
| This AF increased business activities to the locality (e.g., aesthetics, educational tourism) | |
| The presence of large AF landscape brought negative environmental sentiments (e.g., waste dumping) | |
| This AF creates social benefits by providing services such as community meeting places | |
| The community is getting prestige from having a large AF landscapes | |
| Subjective norms | |
| Government and community wanted me to produce this AF only on marginal lands | |
| Local leaders and government officers would expect me to produce AF to improve my livelihoods | |
| I sense the social pressure to engage in producing this AF | |
| Perceived behavioral control | |
| The land resources available make my engagement in AF readily | |
| I can easily engage in producing this AF (e.g., due to available skills) | |
| Market access makes my engagement in this AF more attractive and accessible | |

## XII. RISKS AND UNCERTAINTY

1. What are the major problems you are afraid of AF production/adoption decision? Please describe in order of severity (with likert scale of 0 to 10) a. flood and raining (_) b. Drought (_) c. AF product price fluctuation (_) d. Tenure security (_) e. Input price increment (_) f. Relationship with business people (_) g. Relationship with neighbors ||community (_) h. Decreasing demand (_) I. Availability of optional products (_)
2. Can you please list down the risk sources and their severity you encountered in the previous AF production seasons

| Risk type | | 2011 | 2010 | 2009 | 2008 | 2007 |
|---|---|---|---|---|---|---|
| Input price | Seedlings (ETB) | | | | | |
| | Labor (ETB/person) | | | | | |
| | Fertilizer (ETB) | | | | | |
| | Land rent (ETB) | | | | | |
| | Sharing in land | | | | | |
| Output price | Charcoal (ETB/sack) | | | | | |
| | Wood(ETB/load) | | | | | |
| | Fuel wood (ETB/unit) | | | | | |
| | Litters (ETB/metric) | | | | | |
| Production | Weather change[1] | | | | | |
| | Yield reduction | | | | | |
| | Pests[1] | | | | | |
| Marketing | Large number of brokers[1] | | | | | |
| | Long chain of marketing[1] | | | | | |
| | Poor market information[1] | | | | | |
| | Increased tax (with rate e.g., birr/plant) | | | | | |
| | Huge supply[1] | | | | | |
| | Alternative products[1] | | | | | |
| | Low demand[1] | | | | | |
| | Poor contractual system[1] | | | | | |
| | Lack of contractual buyer[1] | | | | | |
| | Poor marketing place[1] | | | | | |
| Financial | Absence of financial institution[1] | | | | | |
| | Late delivery of cash by wholesalers[1] | | | | | |
| | Impartial delivery of cash by wholesalers[1] | | | | | |
| | Lack of cash for labor[1] | | | | | |
| | Credit bureaucracy[1] | | | | | |
| | Lack of trust from relatives to lend money[1] | | | | | |
| Policy regulations | Product movement (political instability)[1] | | | | | |
| | Product movement (legalization) [1] | | | | | |
| | Lack of production insurance[1] | | | | | |

[1]Likert ; 0= not at all, 1= Very low, 2=poor, 3=medium, 4= high, 5, extremely high

XIII. EXTENSION SERVICES

1. Did you get help or advice from DA's about AF production? 0. No 1. Yes
2. Did the extension agent visit you in the last cropping season? 0.No 1.Yes
3. If yes, frequency of visit?___________________time per working months
4. What was the content of the extension service on AF production? 0. Delivery of improved species 1. Diseases management 2. Improving management practices 3. Marketing 9. Specify_____________________________
5. Have you ever attended a field day on improved AF demonstration? 0. No 1.Yes
6. If yes what was the demonstration all about? _______________________________________________________
   _______________________________________________________________________________________________
7. Have you ever attended a farmer-training course on AF production? 0.No 1.Yes
8. If yes what was the training all about? _____________________________________________________________
   ________________________________________________________________________________________________
9. Did the extension service provide any inputs or training to modify the package? 0.No 1.Yes
10. If yes what were the inputs? _____________________________________________________________________

_______________________________________________________________________________

XIV. CREDIT

1. Have you accessed credit for the last five years? 0. No 1. Yes
2. If yes, source of credit? 0. Cooperatives 1. Amhara credit and saving institute(ACSI) 2. Relatives / friends / neighbors 3. Church 4. Eder 5. Ekub 9. Others________________________________
3. Was the purpose of credit for AF production/operation? 0. No 1. Yes
4. If yes, for what operations did you accessed it and how much of the credit was used for each AF production operation? _______________________________________________________________________.
5. If you have not accessed, why? 0. No institution that provides credit 1. High interest rate 2. Lengthy procedure 3. Collateral requirement 4. Repayment terms are unfavorable 5. Very high down payment 6. No need 9. Others, specify__________________________________________________

XV. AF MARKETING

1. Where did you buy AF inputs (fertilizer, improved tree species, varieties) ? 0. Cooperatives 1. Nearest local market 2. District market 3. Zonal market 4. Regional Market 5. Others, specify____________
2. What are the major constraints related to AF input marketing? 0. Input unavailability 1. Timely unavailability 2. High prices 3.distance to markets (far away) 4. Cheating by artificial pricing 5. any other____________
3. When or after how many years do you harvest the AF? Or will it be matured?_________________________
4. Where do you sell it? 0. Live on the plot 1. By taking to the market 3. Contractual buyer 4.Any other_______________________
5. Do you have a customer or do you sell to an arbitrary consumer? 0. Arbitrary 1. Customer. if any customer, what is his/her role? 0. Retailer 1. Wholesaler 2. Carpentry or wood workman 3. any other______________
6. If any, what arrangements do you make with the buyer? 0. Prepaid 1. Contractual 2. No arrangements 3. Sell with credit 4. any other_______________________________________
7. What other benefits do you get from your customers? 0. Species recommendation 1. Input delivery 2. Investment capital 3. Any other________________________________________
8. Do you have standards and grading for pricing of different sizes and qualities of the products? 0.no 1. Yes
9. If yes, what are those standards and how are they decided?___________________________________________ _______________________________________________________________________________
10. Are you a price taker or price fixer? How it is decided? Is there negotiation or a fixed system?__________ _______________________________________________________________________________
11. How do you get information about prices of AF outputs? 0. From neighbors 1. From cooperatives 2. From radio 3. From market 4. From traders 5. From brokers 9. Other, specify______
12. What are the major constraints related to AF output marketing? 0. Price drop after harvest 2. Distant Markets 3. Transportation problem 4. Lack of latest information about prices 5. Limited numbers of traders for more opportunity to negotiate 6. Cheating by brokers and traders on price 7. Any other

XVI. SOCIAL CAPITAL

Bonding and bridging social capital

1. How many relatives (kinship) do you have? _____________
2. How many intimate friends do you consult or talk about AF? _______________________________
3. What is the relationship with the friends you talk about AF? _________________________________ _____________________________________________________________________
4. With how many friends you share AF inputs? ______________________________________________________ _______________________________________________________________________________
5. How many intimate friends do you have that you share AF experiences or learn by visiting their farms? ______ _______________________________________________________________________________
6. If you suddenly needed money for AF, how many people who would be willing to provide this money (without interest)? _______________________________________________________
7. If you want collective labor during critical labor shortage time for AF, how many people are willing to come to help you?_______________ (Relatives____ and ______Friends)
8. Can you please name an individual who motivated you to adopt the specified AF innovation____________

Can you please his/her location, responsibility and relationship ______________________________________
______________________________________________________________________________________

## Linking Social capital

1. Level of linkage with the following stakeholders for the AF innovation (please mark)

| Stakeholders | Measurement* | Role played for AF adoption |
|---|---|---|
| District office of Agriculture | | |
| Research center | | |
| District Administrators | | |
| NGO's(representative) name | | |
| Local gov. office | | |
| Development Agent | | |
| Civil servant | | |
| Business person | | |
| | | |
| | | |
| | | |

* 0=No at all; 1=very low; 2=low; 3= medium; 4=strong; 5=very strong

## Groups

1. Level of participation in the following informal and formal organizations

| No. | Informal organizations | Membership* | Contribution/role played for AF adoption |
|---|---|---|---|
| 1 | Mahiber | | |
| 2 | Senbete | | |
| 3 | Edir | | |
| 5 | Ekub | | |
| 6 | Cooperative | | |
| 8 | Kebele administration | | |
| 9 | Development Group | | |
| 12 | Farmers research group | | |
| 13 | Others | | |

* 0=Not a member;1=passive participant; 2= active participant; 3=chairman/manager

2. Whenever you want AF related resources, whom do you contact first? 0. Extension agent 1. Researcher 2. Service Cooperatives representative 3. Private traders 4. PA chairman 5. Farmer's research group leader 6. Relatives 7. Friends 9. Other specify_______________
3. Do you agree that the cooperation among stakeholders is central to better adoption of AF? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
4. Do you agree that local organizations are more important for AF adoption than other stakeholders? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
5. Do you agree that market is more important for adoption than stakeholders' involvement? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong

6. Do you agree that a farmer's experimentation and long experience is more important for adoption than research lead results? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong

## Collective action and Cooperation

1. In the 2010/11 cropping season, have you worked with others in your AF production for your or community benefits? 0. Yes 1. No
2. If yes, how many times? _____________
3. What was the major issue the collective action was required in AF production? 0. Clustering the plots for AF production only 1. Pest control 9. Any other, ____________________________________________________
4. What proportion of the community participated towards solving the problem? 0. No one 1. Third of them 2. Less than half 3. Half 4. More than half 5. Two-third 6.Almost everyone
7. Suppose something unfortunate happened to someone in the member of your community of residence or farming area, how is the spirit of the community/member to help him/ her? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
8. How is the extent of giving or exchanging information on AF among your community? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
9. How much is that the community abided by norms and bylaws on AF? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong

## Trust (personal and stakeholder; please write if not at all)

1. Do you trust that most people in your community are willing to help if you need help? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
2. Do you agree that people generally trust each other in matters of lending and borrowing money for AF operation? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
3. Do you agree that stakeholders readily cooperate to benefit farmers on AF production system? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
4. Do you agree that all partners/stakeholders contribute what is expected to improve benefits from AF? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
5. Do you agree that innovations from research system are more trustful than from other stakeholders? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong
6. Do you trust and adopt AF innovations from friends and relatives than from other stakeholders? 0. Not at all 1. Very poor 2. Poor 3. Medium 4. Strong 5. Very strong

## XVII. OFF-FARM OR NON-FARM ACTIVITIES

1. Do you involve in off/ non- farm activities? 0. No 1. Yes
2. If Yes, type of off and non-farm activities and their contribution for monthly/annual income
   a. Petty trade_____________________
   b. Salaried employment_______________
   c. Handcraft___________________________________
   d. Grain and livestock trade______________________________
   e. Other

## XVIII. LIVELIHOOD AND INCOME STRUCTURE

1. Estimated subsistence (take the last five years averagely)

| Income source | Rank subsistence | Cash income in the past year |
|---|---|---|
| Farming (other cereals) | | |
| Forest products | | |
| AF (the specific) | | |
| Livestock | | |
| Remittances | | |
| Fruits | | |

| | | |
|---|---|---|
| Cash crops | | |
| Potato | | |
| Any other | | |

2. What do you think was the major livelihood of your family for the past decade? 0. Potato production 1. Crop production other than potato 2. Animal rearing 3. Forestry (plantation) 4. Other off farm activities like apiculture, poultry 5. Nonfarm activities like black smith and pottery 6. Trading (shops and local cafes) 7.Chat production 9. Other

XIX. ACCESS TO INFORMATION

1. What has been the role of the following information resources for AF adoption and production? And how frequently does the household interacted with these sources?

| Media | Major service | Frequency (per week/mth/yr) |
|---|---|---|
| Mobile phone/landline | | |
| TV | | |
| Market visits | | |
| Interaction with gov. officials | | |
| Religious centers | | |
| Community assemblies | | |
| Other | | |

2. Do you have any suggestions on improving AF production and productivity?_____________________________________
_____________________________________________________________________________________________
_____________________________________________________________________________________________

XX. HOUSEHOLD DECISION MAKING PATTERN

1. If a household member other than the head has major effect on decision making, please specify.

| Member relation | Age | Proportion* | Member relation | Age | Proportion* |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

XXI. POLICY AND REGULATIONS

1. What policies and regulations exist for the specific or general AF production and marketing?_____________
_____________________________________________________________________________________________
_____________________________________________________________________________________________
2. Do you know that AF production is restricted to specific land contexts? ) 0. No 1. Yes. What are they?
_____________________________________________________________________________________________
_____________________________________________________________________________________________
3. If yes, do you follow the guidelines for engagement? 0. No 1. Yes. If no, why?
_____________________________________________________________________________________________
_____________________________________________________________________________________
4. What regulations facilitated AF production or adoption? _____________________________________________
_____________________________________________________________________________________________

## Appendix G: Checklist for key informants and focus group discussion participants

I. General

1. What is the major livelihood in your locality? Could you explain the progress of livelihood change over the last couple of years? What are the major problems faced in these years for improving livelihoods? What actions were undertaken? Can you list down the most important resources of this area that can be used for improving livelihoods of the community?

II. Agroforestry as a livelihood

2. What major events and times have happened in the area in terms of agroforestry practices ( it should be specific to acacia, bamboo or eucalyptus)
3. What is the perception and attitude of the community on the production of agroforestry in comparison to crop /livestock production
4. Could you please list down the major factors that facilitated the expansion of the specific agroforestry innovation?
5. What factors/conditions derailed or is hindering the expansion of the specific agroforestry?
6. How was this agroforestry introduced/brought into the area? When and how it expanded to the community?
7. What is the trend of production of the specific agroforestry in your area? And what are the outlooks of production?
8. What development and policy interventions do you recommend to foster the production and benefits from the specific agroforestry?
9. How important is this agroforestry practice to the overall livelihood of the community? Can you rank accordingly with the major livelihood sources?
10. What is the other (e.g., environmental) benefits of this agroforestry? Does the presence of the agroforestry create conflict among farmers whose plots share common borders/are adjacent? Please list down.

III. Effects on local production system

11. Could you please describe the difference in productivity of normal crops in your locality after the expansion of the specific agroforestry

IV. Processing and marketing

12. Does most of the community members in your locality sale their agroforestry products as raw or processed? Why most of the community sells as raw or processed? Is the market demand governing the type of product delivered?

V. Institutional support

13. What kinds of extension support/advisory services you got from government and NGOs?
14. Can you list down other institutional support services provided by organizations (e.g., organized seed supply, credit, training on processing)
15. What should be the contribution of the government, NGOs and the local communities? Please describe for each separately.
16. What shall be done to bring every household of the communities into participation?

VI. Linkages

17. Do you think that linkage with any one of the organizations in your locality is important? If yes, how? Can you please list down the organizations and the type of linkages that has to be done to ensure benefits of the agroforestry practices?
18. What customary institutions and organizations exist for the management of land?

19. What formal rules and regulations as well as organizations exist for the production of agroforestry practices in your area? Do you know any government regulations that describe the production of agroforestry in your plots? If yes, please list down.
20. What shall be done to scale up these kinds of agroforestry practices in other communities? What shall be done to foster adoption of other kinds of agroforestry technologies in your community?

Appendix H: Certificates from participation in the workshops of the Graduate Academy

- Funding Opportunities for Early Career Researchers-Illustrated by DFG Research Grants: 28th November 2019.
- Horizon 2020: proposing a joint EU research project: 25th November 2019
- Research Data management: 4th march 2020
- Communicating Science: Write, Tell and Pitch Your Research: 14th-15th January 2020
- GA Money Monday: Funding Your Doctorate-Understanding Funding Announcements and Mastering Grant Applications: 24th February 2020

PROPOSITION

1. Agroforestry innovations (AFI) adoption is influenced by diverse factors belonging to individual farmers, institutions and the features of the innovations
2. Discrete studies have provided plethora of suggestions as development and policy inputs
3. These plethora of factors have become problematic for development actors and policy makers as the actors irresolutely contemplate which one to choose and to act on. And when they choose and act, the results are not often satisfactory
4. Process analysis exposed the complete adoption process or patterns of adoption behavior
5. Econometric and Bayesian scrutiny coupled with thematic analysis deepened our understanding of the factors influencing frequency and likelihood of AFI adoption.
6. Financial analysis also proved the viability of investments in AFI
7. It is vital to refine existing frameworks to guide future adoption research to affect policy and actions

Note on the commencement of the doctoral procedure

1. I hereby assure that I have produced the present work without inadmissible help from third parties and without aids other than those stated; ideas taken directly from external sources are identified as such

2. When selecting and evaluating the material and also when producing the manuscript, I have received support from my advisors

3. No further persons were involved in the intellectual production of the present work. In particular, I have not received help from a commercial doctor adviser. No third parties have received monetary benefits from me, either directly or indirectly, for work relating to the content of the presented dissertation.

4. The work has not previously been presented in the same or a similar format to another examination body in Germany or abroad, nor has it – unless it is a cumulative dissertation – been published

5. If this concerns a cumulative dissertation in accordance with Section 10 Para. 2, I assure compliance with the conditions laid down therein

6. I confirm that I acknowledge the doctoral regulations of the Faculty of Environmental Sciences of the Technische Universität Dresden.

   Tharandt, 05.07. 2023