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Smallholder Farmers, Environmental Change and Adaptation in a Human-Dominated Landscape in the Northern Highlands of Rwanda

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SMALLHOLDER FARMERS, ENVIRONMENTAL CHANGE AND ADAPTATION IN A HUMAN-DOMINATED LANDSCAPE IN THE NORTHERN HIGHLANDS OF RWANDA

by

Apollinaire William

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Dedication

First and foremost, to my parents for their unfailing support throughout my life. To my family and friends for having my back throughout this study.

To each of you from whom I have gleaned academic and professional experience, I dedicate this work.

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Abstract

Climate change and crop intensification are key challenges to the livelihoods and wellbeing of the majority of rural smallholder farmers in developing countries, particularly in human-dominated, climate-sensitive landscapes such as the northern highlands of Rwanda where issues of fluvial floods, soil erosion pose serious threats to the livelihoods of smallholder farmers. In this mixed methods study conducted between August and December 2015, I explored smallholder farmers' perceptions by examining what barriers might hinder the process of agroforestry adoption by smallholder farmers, what socio-economic and physical factors and attitudes influence crop choices, motivations for smallholder farmers' willingness to plant trees within riparian buffer zones and opportunities and challenges to the establishment of riparian buffer zones that maintain ecosystem services. Results indicate that challenges to adoption of agroforestry to support climate change adaptation and food security in Rwanda are related to land scarcity, poverty, limited technological and financial capacity among most smallholder farmers, limited engagement of smallholder farmers in agroforestry research and an inclination for short term benefits that could hinder adoption of agroforestry which has a long term investment. Most smallholder farmers believed that the onset of short rains comes earlier in recent years compared to more than ten years ago. In response, most farmers reported that they plant crops earlier in the season. Results from rainfall analysis, although not conclusive, show a shift in rainy day frequency. Respondents who strongly agreed that soil erosion within farms proximal to streams is a serious threat were more likely to support the idea that establishing a riparian buffer would help entrap sediments and mitigate soil erosion within farmlands adjacent to streams. However, farmers reported that establishing a functional riparian buffer requires

engagement with extension services, financial incentives and technological assistance. Perceptions of costs and benefits of riparian zone management was found to be the most important factors influencing farmers' intentions to manage riparian zones. Engagement of smallholder farmers in the agrarian policy development process and their active participation in the implementation of adaptation strategies may be needed in order to provide an opportunity for farmers to learn technologies involved and assess costs and benefits of the practices. This would also insure that smallholder farmers' goals and interests are met.

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Chapter 1: General Introduction

Our planet's climate continues to change at an unprecedented rate. Vulnerability to impacts associated with climate change is adding to ongoing environmental and socio-economic challenges particularly in tropical areas where many societies are dependent on resources that are sensitive to climate change. Climate change has political, socio-economic and environmental effects, in developed countries as well as in developing countries. However, effects are most felt in developing countries, particularly in Africa, due to the magnitude and frequency of extremes weather events such as floods and droughts that overwhelm some poor nations' ability to adapt or mitigate it (IPCC, 2007; Toulmin, 2009; Collier et al., 2008; Omambia & Gu, 2010).

Soil degradation and erosion in Africa are considered to be more rapid and extensive than in other continents of the globe because of the generally high population pressures and land-use intensity resulting in higher nutrient exports through crop removal with significantly lower percentage of arable land under fallow (Mortimore & Harris, 2005). Global river runoff is believed to have increased significantly since the 20th century due essentially to deforestation, and is particularly evident in many African countries. Changes in the distribution of river flows and groundwater recharge over space and time are determined by changes in temperature, evaporation and, crucially, precipitation (Chiew, 2006; Fu et al., 2007). Deforestation of tropical forests, at the rate of about four million hectares every year in Africa (Low, 2005), decreases litter and canopy leaf cover that otherwise intercepts rainfall, facilitates water infiltration, and reduces runoff (Moutinho & Schwartzman, 2005), exacerbating storm events on the continent. Increasing demands for agricultural land, coupled with land scarcity in some countries has led to conversion of natural riparian buffers to crop cultivation, thus compromising the ability of buffer zones to buffer the effects of floods, control sediments, trap nutrients and maintain stream bank stability. The total rainfall from intense precipitation events is expected to increase over most areas, particularly in tropical and high latitude areas (Solomon et al., 2007), exacerbating this problem. It follows that flood frequency and magnitude is projected to increase in the regions experiencing increase in precipitation intensity (e.g. Meehl et al., 2007). Some drainage basins are projected to experience increases in flood frequency (Kundzewicz et al., 2008). These changes influence the ability of ecosystems to provide services to people living off these lands. This is particularly problematic where so many people rely on rainfed agricultural for a subsistence lifestyle.

Ecosystem services are tangible and intangible benefits derived from the functioning of ecosystems, which include flood and soil erosion control, sediment and nutrient control from runoff, pollination, food and fuel production, carbon sequestration, in agricultural landscapes (Swinton et al., 2007; Zhang et al., 2007; Felipe Lucia et al., 2014; Egoh et al., 2008). Agricultural ecosystems can be managed effectively to optimize provisioning ecosystem services (MEA, 2017), which are reliant on a number of regulating ecosystem services including soil fertility and pollination, as inputs to production (Zang et al., 2007). Despite the merits of regulating ecosystem services, agriculture intensification programs in many African countries have not sufficiently incorporated those benefits in policy development. The lack of integration of regulating ecosystem services has resulted in soil fertility loss, soil erosion and water degradation (Zhang et al., 2007), thus reducing the capacity for smallholder farmers to adapt to climate change in many African countries.

Climate adaptation strategies to restore and maintain ecosystem services within agricultural landscapes include but are not limited to intercropping which consists of mixing two or more crops in one field during same crop season, afforestation, agroforestry and the establishment of functional riparian buffer zones around water bodies. Agroforestry has the potential to improve soil fertility and contribute to alleviating pressure on natural forests by providing fuel wood and timber. Agroforestry can also provide fodder for livestock and sticks to support climbing beans, medicine, handicraft raw material and plant disease control. In agricultural landscapes where slopes are steep or where crop cultivation has seriously encroached on riparian zones, studies show that agroforestry is the most naturally appropriate practice to conserve soil stability against erosion, fertility and control nutrient leaching and sediments from rushing into streams. In agricultural landscapes where agricultural intensification is associated with intensive use of industrial fertilizers, riparian buffers contribute to trapping sediments and nutrients such as phosphorus and denitrify nitrites, thus contributing to water quality in streams.

Owing to their multifunctional roles, trees and woodlots on farms are now considered in the preparation of the Global Forest Assessment 2015 (FAO, 2010b). The idea of sustainable management of natural resources extends beyond forests to apply to trees outside forests as well (Kleinn, 2000). The general objective is to explore farmers' perceptions of climate variability, adaptation and barriers to adaptation.

The adoption of agroforestry by smallholder farmers in developing countries poses challenges, especially for low-income, uneducated farmers. The uptake of agroforestry is hindered by a number of factors including lack of technical and financial capacities to implement the practice effectively. In many places, agroforestry is administered from above in a top-down approach without gauging farmers' interests and goals and without equipping farmers with necessary tools, skills and financial means required for the success of the practices. Studies show that agroforestry, like any other agricultural practice, can be adopted by farmers if they see its effectiveness in term of cost/benefits ratio by monitoring model farm plots, if they have financial means and if they feel empowered enough to practice agroforestry. The farmer makes decisions to plant a buffer based on net crop prices and costs of land or planting. The choice of buffer type is affected by crop price, farm size, relative incentive payments, relative cost share rates, and amount of damage from various sources (Lynch and Brown, 2015).

Understanding farmers' perceptions of the role of ecosystem services within an agricultural landscape, especially how they support sustainable food production and livelihood improvements is key to formulating effective policies that are not only tailored to farmers' needs and goals but also which accommodate environmental concerns. Socio-psychologists suggest that, based on the theory of planned behavior TPB, intentions for a behavior change, for example decision to adopt certain agricultural practices that accommodate ecosystem services, hinges on a number of factors, including perceived behavioral control, attitudes about sustainable management of farming practices that foster both economic and environmental outcomes, and available labor (McGinty et al., 2008). Overall, perceived behavioral control appears to have the most significant correlation with farmers' intentions to adopt or maintain agroforestry for example (McGinty et al., 2008).

Understanding farmers' perceptions of their self-efficacy in management of agroforestry for ecosystem service restoration and maintenance as well as their attitudes, their socio-economic characteristics and their source of experience with the practices, whether through participating with agroforestry programs or through the establishment of functional riparian buffer zones, is essential for sustainable agriculture. Unfortunately, most agricultural policies are designed without participation of farmers and do not necessarily foster synergies between regulating and provisioning ecosystem services within agricultural settings. In a human-dominated landscape there is high reliance on scarce farmland, and in Rwanda, for example, about 57% of farms are less than 0.5 ha (Singh, 2000) with an average farm size of 0.76 ha (Booth & Golooba-Mutebi, 2012). In these cases it is important to explore smallholder farmers' perceptions about ecosystem services generated by sustainable agriculture apart from food, their adaptation strategies and their willingness to adopt agroforestry particularly given scarcity of their land coupled with poverty.

My research focused on Rwanda where the issues of reliance on scarce, climate-sensitive landscapes for subsistence agriculture come together with policies for agriculture intensification that may not consider ecosystem services. Given evidence that the Northern and Western Provinces in Rwanda have been exposed to more frequent and extreme climate events while understanding of climate variability and adaptation remains limited, studies of farmers' perceptions of climate variability and barriers to adaptation could shed light on development of effective adaptation strategies. I examined farmers' perceptions of climate variability in the Upper Mukungwa Watershed and their adaptive responses. Socio-economic and psychological barriers to farmers' adaptation are discussed, incorporating perspectives of farmers and from existing literature. Data were obtained from smallholder farmers' interviews. Recorded rainfall data at the Kigali meteorological station based at the Kigali International Airport from 1971 to

2013 are also incorporated to demonstrate the actual climate variability of the region. Hopefully, this study helps enhance understanding of the adaptation process at farm level, particularly in the Musanze District with focus on crop choice, timing of planting, agroforestry and riparian buffers for ecosystem service restoration and maintenance.

In Rwanda, the problems of land degradation coupled with climate change impacts, which translate into landslides, floods, soil erosion, stream channel degradation, and scarcity of arable land come together to create vulnerability among small holder farmers. Riparian zones have been stripped of their natural vegetation in favor of food crop cultivation. While the Rwandan government has introduced a crop intensification program and has set up regulations about protection of riparian zones around streams and lakes, information about farmers' perceptions about government efforts as well as their beliefs about factors that could potentially contribute to maintaining ecosystem services within riparian buffer zones has not been well documented. My research aimed at examining farmers' perceptions regarding climate change, adaptation and barriers to adaptation, and provides state-of-the art information about the status of agroforestry in Rwanda by: (1) examining perceptions of climate change and adaptation, (2) examining the status of agroforestry in Rwanda and (3) identifying socio-economic factors that contribute to farmers' intentions to grow particular plant species within riparian zones on their farms.

My research contributes to the theoretical literature and provides recommendations for future research and policy direction with respect to maintaining ecosystem services, whether provisioning or regulating, within agricultural landscapes. To achieve the main goals of this research project, I focused on the following research questions:

1) What are the barriers that might hinder the process of agroforestry adoption by smallholder farmers given historical and present status of agroforestry in Rwanda?

2) What are the socio-economic and physical factors and attitudes that influence the choice of food crops to plant in a given season?

3) What are the motivations and main purposes that drive smallholder farmers' willingness to plant trees within riparian buffer zones on their farms?

4) What are the opportunities and challenges to establishing riparian buffer zones that maintain ecosystem services?

A better understanding of the determinants of household choice of adaptation strategies such as the timing of crop planting, the choice of food crops to plant, and the choice of trees to plant for riparian buffers was analyzed using the theory of planned behavior (TPB) conceptual framework and empirical models to assess motivations for agroforestry adoption and ecosystem service maintenance. The dissertation aims to clarify these dependencies through the combined use of comprehensive farm and household level studies coupled with farm agroforestry assessment, to analyze the relevance of agroforestry in meeting the needs for maintaining ecosystem services for climate change adaptation.

The dissertation consists of five chapters. Chapter 2 presents a review of agroforestry in Rwanda and assesses the potential of agroforestry systems to provide multiple benefits to smallholder farmers. I explored the literature on agroforestry in the face of climate change adaptation and food security in a human-dominated, climate sensitive landscape of the northern highlands of Rwanda. I also reviewed opportunities and challenges pertaining to the adoption of agroforestry in Rwanda. Chapter 3 provides an assessment of smallholder farmers' perceptions of the onset of rainy seasons and the timing of crop planting as well as the level of vulnerability of currently cultivated crops to climate change. In this chapter, I also assessed smallholder farmers' willingness to adopt agroforestry and examined the relationship between their willingness to adopt agroforestry for climate change adaptation and socio-economic factors. Chapter 4 provides an understanding of farmers' views and experiences about the importance of ecosystem services, and strategies for restoring and maintaining those ecosystem services in riparian buffer zones. It discusses the reasons why farmers choose to plant particular trees in riparian zones on farmlands and identifies the most important aspects that households consider when deciding to plant a variety of different trees species in agricultural lands. Chapter 5 summarizes findings and key discussion points teased out from previous chapters. In this chapter, I formulate recommendations and suggestions for future research as well as the way forward regarding policy directions.

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Chapter 2: The potential and challenges of agroforestry to support climate change adaptation and food security in a human-dominated, climate sensitive landscape

Abstract

Conventional agriculture is the mainstream approach to achieving global food security but has also caused extensive environmental and social harms. Recent consensus shows we need to move away from the current, narrow focus on yield toward an agriculture that accommodates and enhances environmental goals which in return can support agriculture. Such a shift could also enhance climate change adaptation. As the effects of climate change on agricultural activities of small holder farmers in rural developing regions become more evident, attention on the potential of agroforestry for adaptation and food security has heightened. Increasing human populations in many developing countries are placing greater pressures on natural land cover, creating human-dominated landscapes with reduced ability to sustain biodiversity and ecosystem services such as water retention, carbon sequestration, and soil fertility. In the face of increasing land scarcity for agricultural purposes in many African countries, agroforestry has been proposed as an alternative for restoring some of the emergent ecosystem services originally provided by natural forests. In this review, I explore the potential for and constraints to adoption of agroforestry practices to support climate change adaptation and food security. I focus this review on the case of smallholder farmers in Rwanda, a country that has undergone significant recent and rapid transformations in agriculture, economic development and land degradation. Although agroforestry practices were imposed on Rwandan farmers during the colonial period, implementation of agroforestry has slowed in Rwanda since its independence in 1962. Factors that contributed to the slow adoption of tree planting on farms include socio-economic constraints, land scarcity, lack of access to input capital and seedlings, and low income. In the

face of land scarcity, farmers prefer particular species based on local socio-economic needs, agro-ecological suitability, growth rates to avoid competition with other food crops. However, agroforestry practices are not necessarily driven by environment concerns. This gap could be bridged by proposing agroforestry practices that contribute to environmental sustainability and meet farmer's goals without being risky. Two-way knowledge transfer between farmers, agronomists and ecologists in a participatory approach helps to encourage an agroforestry management regime that balances economic and ecological needs and provides a diversified food and cash crop livelihood strategy.

Key-Words: agricultural intensification, ecological-economic trade-offs, fuel wood, multifunctional trees, perceptions, smallholder farmer, soil fertility, water quality

Introduction

Agroforestry is defined as land-use practices that deliberately combine woody perennials with animals and/or crops on the same managed land (ICRAF, 2010). Increasingly agroforestry is viewed as providing ecosystem services, environmental benefits, and economic commodities, including net primary production, pest control (Schroth et al., 2000; Altieri & Nicholls, 2003), pollination and seed dispersal (Varah et al., 2013), soil enrichment (Ilany et al., 2010; Konig, 2007), soil stabilization and erosion control (Atangana et al., 2014a; Roose & Ndayizigiye, 1997; Narain et al., 1997), clean water (Jose, 2009; Udawatta et al., 2010), flood mitigation (Matocha et al., 2012), carbon sequestration (Montagnini & Nair, 2004), maintenance of biodiversity (McNeely, 2004) and aesthetic and cultural values. Published work provides evidence of the role of agroforestry in supporting water quality, controlling erosion, enriching soil and diversifying farming systems by producing timber, fruits and non-timber forest products (NTFPs) or other commodities (e.g. Rice, 2008). The diversity of products provided by agroforestry can in many cases help meet the needs of smallholder farmers for fuel wood, food, livestock fodder, and other household and farm needs. These products can provide additional income to supplement commodity crops and can offer flexibility in production and income to buffer the effects of changes in commodity prices and markets, crop failure, or other sources of financial or economic difficulty (Idol et al., 2011).

In most African countries, the merits of agroforestry for climate change adaptation and maintenance of ecosystem services among smallholder farmers are increasingly being recognized (Roose & Ndayizigiye, 1997; Johansson et al., 2013; Nyasimi et al., 2014; Pattanayak et al., 2003; Konig, 2007). However, in some countries government policies can work against practices that promote maintenance of ecosystem services such as agroforestry. In Rwanda, for example, a government-mandated crop intensification program based on monocropping systems and conversion of marshlands to rice cultivation has been extensively adopted by smallholder farmers since 2007. Although the program has resulted in crop production increase since its implementation (MINAGRI, 2011), recent studies have revealed that such practices are detrimental for the environment in the long run, with adverse impacts on soil conservation and food crop production (Gomiero et al., 2011; Vaast & Somarriba, 2014; Cole et al., 2015). Existing literature on agroforestry in Rwanda has only emerged near the end of the 1900s (e.g. Yamoah & Burleigh, 1990; Yamoah & Grosz, 1988; Drechsel et al., 1996), and has focused essentially on food security and ecosystem services that support food production; little attention has been paid to the climate change adaptation element (Bucagu et al., 2013). In landscapes that are climate-sensitive, that is sensitive to the variability of climate and seasons, it is crucial to review some of the strategies geared toward climate adaptation.

In this chapter, I review the role of agroforestry in balancing human needs with environmental benefits, and discuss the potential ecological and economic benefits of appropriate management. I explore the historic and current state of agroforestry and its adoption by smallholder farmers facing climate change and government-mandated agricultural intensification policies in Rwanda, a human dominated climate sensitive landscape. I assess current agroforestry practices adopted by Rwandan farmers, and the constraints and incentives associated with such practices. Finally, I conclude the chapter with suggestions on steps towards sustainable adoption and management of agroforestry in Rwanda and other developing countries that is financially profitable and environmentally sound, including future research horizons.

Colonial and post-colonial agroforestry in Rwanda

The clearing of land for farming and felling of forests for charcoal production opened up the landscape in Rwanda for pastoralism that started around 1400 (Page & Daves, 2005). As the Rwandan population increased, more forested land was cleared for agro-pastoral activities. By the early 1900s, dense forests had decreased to about three percent of the Rwanda-Urundi territory, which included the current countries of Rwanda and Burundi, or 6.5 percent if including savanna areas (Everaerts, 1947). Reforestation consisted of planting trees in woodlots rather than incorporating them into farming systems. Colonial agronomists often considered trees more of an obstacle than an aid for agricultural development and, other than fruit trees and a few economically important woody species such as coffee, tea, and oil palm, they made no mention of trees in their descriptions of farming systems in the region and trees were merely planted in woodlands (e.g. Mortehan, 1918 & Everaerts, 1947, in den Biggelaar & Hart, 1996).

The Rwandan population density grew from 88/km^2 in year 1950 to 313 persons/km^2 in 2000, 414 in year 2012, and is predicted to reach 688/km^2 in year 2050 (MINECOFIN & NISR, 2012). Given the reliance of a vast majority of the Rwandan population on agriculture, and the state of land scarcity for the growing population, forest land and wetlands have been cleared for farming activities, increasing risks of erosion and flooding. For example, between 1960 and 1999, Nyungwe forest lost about 21.8% of its cover, Mukura forest lost 46.7%, Birunga forest lost 62.5% and Akagera savanna woodlands lost 66.3% (MINITERE, 2005).

In order to protect soil against erosion as a result of intensive agriculture and overgrazing, the Belgium administration agricultural service implemented an erosion control program in

1926. The agriculture program developed by the Belgian administration was conceived not only to control erosion, but also to prevent famines like those which occurred in Gashogoro in 1904, Kimwaramwara in 1906, Kazuba in 1910, Rumanura in 1917-1918, and Gakwege in 1924-1925. Recommendations included anti-erosion hedges planted in levelled curves on at-risk slopes. A program of re-forestation was thus established. It was not until the 1930s that active planting of trees began when Belgian colonists introduced non-native species such as *Eucalyptus spp., Grevillea robusta,* and *Cupressus lusitanica*, mainly in woodlots. The main purpose of the endeavor was to reforest areas that had been degraded following heavy deforestation. Everaerts (1947) estimated the total area reforested with non-native tree species at the end of 1938 at 22,000 ha, with 9,723 ha in Rwanda. Communities were obliged to establish one hectare woodlots per 300 people each year in order to combat shortages of fuel wood and timber (den Biggelaar & Hart, 1996). Therefore, these colonial mandated agroforestry approaches focused on woodlots rather than including trees in agricultural fields.

After the 1962 independence of Rwanda, tree planting slowed because farmers considered slopes to be stabilized enough by planting *Pennisetum sp.,* used to counteract erosion. The new Rwandan government of independence encouraged intercropping using *Pennisetum sp.* which was used as fodder, support for beans and as fuel material for cooking (Rossi, 1998). Intercropping here refers to the systematic planting of two or more crops on the same field. Also during this time, various agriculture development projects emphasized the establishment of terraces, the planting of species that contribute to erosion control around farmlands and the establishment of *Eucalyptus* plantations, but farmers often abandoned the practices despite awareness campaigns about the usefulness of modern farming practices because it was considered a measure imposed by the colonial administration (Sibomana and Moeyersons, 1996). A 2010 survey of farmers' impressions of changes in tree cover during the previous 10 years in Rwanda showed little difference in the proportion of households that reported an increase in tree cover (44%) and a decline in tree cover (46%) for the whole study area, suggesting that the uptake of agroforestry has not been as extensive as is often suggested (Ndayambaje et al., 2012). Some research shows that slow adoption of some agroforestry techniques by farmers in Rwanda is explained by socio-economic factors (Ndayambaje et al., 2012; Salam, Noguchi, & Koike, 2000; Arbuckle et al., 2013; Dang et al., 2014) and limited capacity for government extension services to engage farmers effectively with respect to the uptake of the agroforestry technology.

The development of agroforestry in Rwanda is among the guiding principles of the current forest policy (MINIFOM, 2010). Since 2011, the Rwanda government has paid particular attention to agroforestry by promoting tree planting on farmlands in order to curb depletion of forest resources, declining soil fertility and environmental degradation, and to contribute to solving the rural energy crisis, land scarcity, and soil erosion problems (Ndayambaje et al., 2012). However, the limited capacity of extension agents to provide adequate agroforestry information to farmers to realize both environmental and economic objectives (MINAGRI, 2011; Stainback et al., 2011; Ndayambaje et al., 2012), combined with limited access to capital investment and microcredits among smallholder farmers (Ansoms, 2010; Huggins, 2009), scarcity of farm land, limited access to extension services and lack of seedlings (Cantore, 2011; MINAGRI, 2011; Isaacs et al., 2016) has hindered uptake of agroforestry practices. Those farmers who have planted trees favor certain tree species that are suitable to local soil and climatic conditions and which address their various needs most of which are economic in nature (e.g. Ndayambaje & Mohren, 2011), suggesting that if these constraints can be overcome, adoption of agroforestry practices could be more successful and sustainable by accommodating environmental concerns related to soil and water conservation.

Efforts to make agroforestry viable should capitalize on the fact that most farmers are now taking steps towards incorporating tree planting into their farms (Ndayambaje et al., 2013). Trees commonly planted today in Rwanda in agricultural settings include *Leucaena sp.* and *Calliandra sp.* which grow at all elevation gradients, *Alnus acuminata* and *Sesbania sesban* which are found mainly in high elevations, and *Cassia spectabilis* which is predominant in lower elevations in Rwanda; *Eucalyptus* and *Grevilea* are found mostly in woodlots on marginal lands (MINAGRI, 1991). *Leucaena sp.* and *Calliandra sp.* are preferred by farmers in various parts of the country (Dusengemungu & Zaongo, 2006) and are believed to contribute to soil fertility restoration (Konig, 2007). Many *Eucalyptus* species have a high coppicing ability (the capacity for a tree to put out new shoots from the stump or roots when main stem is cut), which increases stock density and profitability per unit area (Bagchi & Mittal, 1996; Babitha et al., 2000; Turnbull et al., 2000; Little & Gardner, 2003; Albaugh et al., 2013)**.**

Studies on the role of agroforestry in soil conservation in Rwanda are still scarce (e.g. Roose and Ndayizigiye, 1997; Konig, 2007), despite the concern of widespread and significant soil erosion and degradation (Roose and Ndayizigiye, 1997). The Rwandan government is deploying efforts to restore soil fertility through erosion control measures such as terracing, tree planting, increased use of mineral fertilizers but those efforts generally do not take into consideration poor smallholder farmers' financial and technical capacity needs (Ndayambaje et al., 2012) Bryan et al., 2013; Salam et al., 2000; Hassan et al., 2008) to maximize the output within small farmland plots (Ansoms et al., 2008). This is exemplified by farmers' preferences for certain tree species that provide multiple benefits, examined in the following section.

Multifunctional role of agroforestry in Rwanda

Agroforestry in Rwanda currently consists of seven major categories: boundary planting, contour hedgerows, homegardens, silvopastoralism, woodlots, intercropping/alley cropping and scattered trees on farm (Ndayambaje & Mohren, 2011; Dusengemungu & Zaongo, 2006) (Table 2-1). In some farms a mix of agroforestry practices can be found. Literature about the adoption and distribution of each type of agroforestry practice in Rwanda is scarce (e.g. MINIRENA, 2014), and the valuation of socio-economic benefits at all geographic scales in the country is not available yet. In addition, an understanding of the relationship between various agroforestry practices and provision of environmental benefits for climate change adaptation among smallholder farmers is still lacking. Nevertheless, it is clear that agroforestry offers valuable benefits to smallholder farmers in Rwanda (Nduwamungu, 2011; Konig, 2007; Ndayambaje & Mohren, 2011).

Table 2-1

Agroforestry Practices in Rwanda and their Socio-ecological Functions

Agroforestry type	**Description**	**Geographic distribution where research was done**	**Function**
Boundary planting	Trees planted for delimitation between farms; used as live	Buheruka Highlands,	Erosion control (Konig, 2007) (Roose

	fencing or buffer between roads and farms	Eastern Savannah, Nile-Congo Crest, Volcanic Highlands	& Ndayizigiye, 1997), fuel wood, stakes for climbing beans, fodder (Ndayambaje et al., 2012)
Contour hedgerows	Hedges of trees planted along contour lines, on ditche edges and on cropped bench terraces for stabilization	Buberuka Highlands, Volcanic Highlands	Soil erosion control (Mutegi et al., 2008; Xu et al., 2001; König, 1992), provision of stakes for climbing beans and fodder for animals (Ndayambaje et al., 2012).
Homegardens	Mixes of non-native and indigenous trees with annual or perennial crops (e.g., maize, beans, vegetables, coffee and banana) and livestock to produce products and services in the proximity of the homesteads	Buberuka Highlands, Central Plateau, Eastern Plateau, Eastern Savannah, Nile-Congo Crest, Volcanic Highlands	Soil erosion control, stakes for climbing beans, building material, fuel wood, fodder for animals (Ekise et al., 2013; Ndayambaje et al., 2013)
Silvopastoralism	Complementary relationship between trees and pasture in a forest products and livestock production system	Eastern Savannah, Volcanic Highlands	Soil conservation, fodder for livestock (Barret, 1990; Roose & Ndayizigiye, 1997)
Woodlots	Lots of trees planted primarily for the production of fuel wood, charcoal, building poles and timber. Species typically used include *Eucalyptus* spp., *Cupressus* sp., *Pinus* sp., *Acacia* mearnsii, *Ficus* sp.,	Central Plateau, Eastern Plateau, Easter Savannah, Nile-Congo Crest,	Provision of fuel wood, other timber products, poles, stakes for climbing beans and erosion control. (Ndayambaje et al., 2013)

	Mitragyna rubrostipulosa, *Markhamia* sp., *Grevillea* sp., and *Ricinus officinalis*	Volcanic Highlands	
Intercropping/Alley cropping	Trees planted within agricultural fields such that the food crops are planted between hedges of trees, which are coppiced regularly to reduce competition for light	Eastern Plateau, Eastern Savannah	Erosion control, stakes for climbing beans and reduction of the use of synthetic fertilizers (Yamoah & Burleigh, 1990)
Scattered trees on farm	Trees placed randomly in fields in relatively wide spacing, with the surrounding space used for crops or pasture	Central Plateau, Eastern Plateau, Easter Savannah, Nile-Congo Crest, Volcanic Highlands	Soil fertility restoration, erosion control, provision of fuel wood and other timber products, stakes for climbing beans and fodder for livestock (Ekise et al., 2013)

Agroforestry in Rwanda has the potential to provide multiple benefits to smallholder farmers. For example, an alley cropping experiment in Rwanda with *Sesbania sesban* found that trees seemed to reduce the incidence of maize rust (*Puccinia sorhii*). Disease incidences were lower in areas with hedgerows compared with those without (Lasco, Delfino, & Espaldon, 2014). *Sesbania sesban* is found mainly in high altitudes of Rwanda, and is known for its medicinal properties (Kamel et al., 2011) in addition to providing fodder for livestock (Oosting et al., 2011; Klapwijk et al., 2014), fuel wood and stakes for climbing beans (Roose & Ndayizigiye, 1997). There are other agroforestry species found in Rwanda which perform multiple functions to meet the needs of farmers. These include *Eucalyptus* spp., *Grevilea robusta*, *Alnus acuminata, Calliandra calothryrsus* and *Cassia spectabilis*. Agroforestry supports pollinators that visit agricultural crops. Given the potential of agroforestry for climate adaptation, the following paragraphs discuss challenges and opportunities pertaining to the adoption of agroforestry in the face of climate change and a recent government-mandated crop intensification program.

Environmental benefits of Agroforestry in Rwanda

Despite claims from previous studies on agroforestry and climate change in Rwanda which suggest that agroforestry is effective in strengthening smallholder farmers' ability to adapt to climate change (Stainback et al., 2012; Ndayambaje et al., 2013; Nsabimana et al., 2008; Rockwood et al., 2004), agroforestry has mostly been practiced to provide fuelwood (Ndayambaje & Mohren, 2011) and other products that support food production such as poles to support beans, and fodder for animals (Nahayo et al., 2016). Soils in these agricultural systems continue to degrade and lose fertility through erosion, and the quality of water in streams continues to decline (e.g.,Wali et al., 2011; Nhapi, 2011). However, studies to accurately quantify the impact of agroforestry intervention on soil fertility, erosion and pest control and water quality management are still limited (e.g. (Roose & Ndayizigiye, 1997).

Recent studies on agroforestry in Rwanda emphasize the need to implement agroforestry in farmlands to improve soil productivity (Habiyaremye et al., 2015), and to improve the microclimate within agricultural landscapes for the improvement of crop performance as trees can buffer climatic extremes that affect crop growth (Atangana et al., 2014a; Mbow et al., 2014; Chaudhury et al., 2011; Bishaw et al., 2013; De Souza et al., 2012; Negra, 2013). However, research on agroforestry in Rwanda has not fully covered the whole spectrum of potential environmental benefits such as pollination, pest control, and non-point nutrient-associated pollution control, and field research involving farmers to demonstrate how agroforestry can practically provide such environmental benefits is still limited. At the same time, it is clear that integration of environmental goals into agroforestry policy opens up opportunities for sustainable intensification of agriculture.

Smallholder farmers and Agroforestry: opportunities and challenges to adoption

The government-mandated crop intensification (CI) program initiated in 2007 in Rwanda is aimed at transforming subsistence agriculture into a productive, high value, market oriented sector (Kaberuka et al., 2000; Pritchard, 2013). CI is characterized by a monocropping system associated with intensive use of synthetic fertilizers and conversion of marshlands into rice plantations. The program has resulted in an increase in crop production ever since; corn, beans, Irish potatoes and rice have particularly increased in production (MINAGRI, 2011).

While the CI program seems to perform satisfactorily in terms of increased crop production, scientists have expressed concern over long-term environmentally adverse impacts of such short-term benefit agricultural practices and these impacts are likely to be exacerbated by the effects of climate change (Lasco et al., 2014; Midega et al., 2015; Hassan et al., 2008). A number of studies predict an increase of rainfall and temperature in Rwanda (e.g., Asumadu-Sarkodie et al., 2015; Shongwe et al., 2011; Stocker, 2014; REMA, 2011; McSweeney et al., 2011). Rainfall projections predict an increase of 20% by 2050 and 30% by 2080 (Asumadu-Sarkodie et al., 2015). Mean precipitation for the short rainy season of October-December is projected to increase by more than 10% (Shongwe et al. (2011). There is still no consensus about the magnitude of rainfall increase and some analyses even suggest a slight decline in rainfall (Henninger, 2013).

As a result of climate change, increased vulnerability of agricultural lands to soil erosion and floods is predicted and has started to be experienced, particularly in the highlands of the country (Nahayo, Ekise, & Niyigena, 2013; Zimmerman et al., 2012; REMA, 2011; Musanze District, 2013; SEI, 2009; Wali et al., 2011; Kagabo et al., 2013; Pritchard, 2013). Although studies on climate change impacts on crops are still limited (e.g. Jarvis et al. , 2012), the increase in temperature and precipitation is likely to favor the incidence of pests among crops (Chakraborty et al., 2000; Ghini et al., 2008) which, in a CI system, would require the use of more pesticides. Potatoes, maize and beans, which are among the staple foods for most Rwandans, are predicted to be affected by pests as a result of temperature increases (Jarvis et al., 2012). In addition, increases in precipitation coupled with intensive use of synthetic fertilizers is likely to increase nutrient leaching which impacts water quality in streams and lakes (e.g. Wali et al., 2011; Kimwaga et al., 2012) and land degradation.

Agroforestry has been proposed as a strategy in climate change adaptation within agricultural landscapes (Hassan et al., 2008). In climate-sensitive areas such as Rwanda , it has been recommended that soil loss, which poses a severe threat to agriculture (Konig, 2007) may be dramatically reduced through hedgerow/agroforestry contour planting and improved mulching practices (Verchot et al., 2007). However, agroforestry is more effective in agricultural landscapes characterized by intercropping systems. Results from a study that analyzed determinants of farm-level climate adaptation measures from 11 African countries showed that specialized crop cultivation (mono-cropping) is the agricultural practice most vulnerable to climate change in Africa (Hassan et al., 2008). A recent assessment of the value of diverse cropping systems under the new agricultural policy environment in Rwanda (Isaacs et al., 2016) demonstrated that an improved intercropping system tends to outperform the government-mandated system of alternating single-cropped bean and maize season-by-season.

Despite the potential for agroforestry to provide environmental benefits that can enhance food productivity, its adoption by smallholder farmers is still challenged by a number of factors including scarcity of arable land per household and concerns about high competition for land between forestry and agriculture (Ndayambaje et al., 2013; MINIFOM, 2010), and rampant poverty (Malyon, 2014). In addition, support from extension services which are the main source of agricultural information has so far remained ineffective (Ndayambaje et al., 2012; Stainback et al., 2011) as will be discussed below. Furthermore, while micro-credit schemes in Rwanda, for example, are widespread and are believed to contribute to the efficiency of agricultural production, credit is virtually inaccessible to smallholder poor and uneducated farmers (Nabahungu & Visser, 2013; Ali et al., 2014; Musanze, 2013; Mutandwa & Kanyarukiga, 2016). A study of farmers' perceptions of agroforestry and the restoration of ecological and economic productivity of agricultural land revealed that agroforestry is considered by farmers as too risky (Verdone & Seidl, 2016). The priority of smallholder farmers is to maximize crop production on their land, and they find it risky to invest in woodlots or agroforestry (Atangana et al., 2014; Dyer, 2014; Ali & Deininger, 2015; Chand et al., 2011). Efforts to improve farming systems, including agroforestry, require innovative and inclusive approaches that enable adaptation to the socio-ecological realities of farmers (Isaacs et al., 2016; Larochelle et al., 2016) which can vary from place to place. Agroforestry is a very "knowledge intensive" endeavor (Place et al., 2012). Farmers must learn new skills which takes time, effort and money (Pye-Smith, 2010). Therefore, since profitability is a major driver in adoption of climate adaptation strategies among farmers particularly with respect to the choice of farming systems and crop choice (Chouinard et al., 2008; Musshoff & Hirschauer, 2008; Cary & Wilkinson, 1997), the success of the adoption of agroforestry hinges on its profitability. Financial incentives coupled with support from extension services should lead to profitability.

To ensure the success of agroforestry adoption among poor smallholder farmers, it is critically important to investigate the economic returns from the integration of trees with agriculture in addition to providing financial incentives and technological support. Choosing between agriculture and tree crops can be facilitated by a forest policy that supports strategies that might include mainstreaming agroforestry in agricultural policies, promoting best management practices of trees and woodlots on farms, building capacity of farmers, providing incentives for tree planting, and developing and disseminating farm forestry information and technology (Ndayambaje et al., 2013).

The forest policy could capitalize on benefits that agroforestry could provide to farmers in addition to environmental outcomes. Adoption of agroforestry in Rwanda is possible as long as the ways that it contributes to resolving the increasing demand for fuelwood and other wood products (Kalinganire, 1996; Bucagu et al., 2013) among rural communities, the majority of which are farmers (Ndayambaje & Mohren, 2011) can be demonstrated without compromising food crop production (Ndayambaje et al, 2013). Given the limited capacity among most smallholder farmers to acquire pesticides and synthetic fertilizers, extension services could, through field-based experiments on farmers' land and through farmer-to-farmer extension efforts, collaboratively demonstrate how agroforestry, in association with efficient cropping systems, can significantly cut the use of those chemicals. To bring a positive, substantial impact to farmers, and bring them into durable adoption of agroforestry in the case of this review, requires that experiments involve farmers directly, taking into account smallholder farmers' objectives and constraints (Isaacs et al., 2016).

New perspectives in agroforestry in Rwanda

The economic development and poverty reduction policy documents in Rwanda set clear targets to increase national forest cover to 30% of total land area equivalent to 790,140 ha of forest and to achieve agroforestry cover of 85% of arable lands by 2020. However, due to high population density (507 inhabitants/km2 in 2017), farming land per household is shrinking resulting in high competition for land between forestry and agriculture (MINIFOM, 2010). One of the objectives of the forestry policy is to "contribute to sustainable land use through soil, water and biodiversity conservation, and tree planting through the sustainable management of forests and trees" (MINIFOM, 2010). As farm land per household decreases and soils become exhausted, crop cultivation is being pushed into marginal areas, particularly on steep slopes and riparian zones, leading to widespread landslides, soil erosion and siltation of water bodies (MINIFOM, 2010). Restoring soil conservation on marginal lands and riparian zones through agroforestry are important steps for sustaining food production while fostering other environmental and economic benefits.

Past and most current research on agroforestry in Rwanda has been conducted mostly in experimental fields owned by research institutions (e.g. Dusengemungu & Zaongo, 2006), and capacity building in agroforestry has been provided mainly to government entities without including smallholder farmers (Nduwamungu, 2011). Rwandan policy makers have recognized a need to integrate agroforestry into agrarian policies and strategic plans, and efforts have been made to disseminate best agroforestry practices among farmers in Rwanda by developing farmer and private sector capacity to implement agroforestry effectively, to intensify research on agroforestry technologies and plant species suitable for various agro-ecological zones (Nduwamungu, 2011). While these efforts are valuable, scientists have highlighted the necessity to incorporate farmers' input into the adoption of agroforestry technology. Not only do farmers have knowledge about suitability of local tree species to local geophysical and socio-economic conditions of their area, but also their motivation to plant trees will largely depend on their specific goals and needs (e.g. Ndayambaje et al., 2012; Nahayo et al., 2013).

Extension services and agroforestry adoption in Rwanda

A number of studies in sub-Saharan African have shown that the effectiveness of extension services, in addition to credit access and land, are key to building farmers' capacity and catalyzing their decision to adapt to climate change (Bryan et al., 2009; Hassan et al., 2008; Franz et al., 2010) through the adoption of new agricultural practices that include agroforestry. Extension services often do not reach poor marginalized farmers including women, minorities, and people in very remote areas (Anandajayasekeram et al., 2007). Challenges pertaining to access to good extension services can also be seen in Rwanda.

The important role of extension services in supporting smallholder farmer adoption of agroforestry in Rwanda has been noted in recent publications (Muhongayire et al., 2013; Andrew & Masozera, 2010). However, while the number of extension services has increased in Rwanda, their efficiency has been questioned (Stainback et al., 2011). Given their substantial contribution to wood products in Rwanda, Rwandan smallholder farmers should be well equipped with knowledge and technical skills needed to put in place sustainable agroforestry that accommodates both environmental benefits and economic benefits. Extension services efforts coupled with formal training are some of key channels for the acquisition of knowledge about environmental benefits of farming technologies (e.g., Hussain et al., 1994; Feder & Slade, 1984). Successful agroforestry requires, among other things, that extension services accommodate the variability farmers' specific needs in different regions and social groups across the country (Stainback & Masozera, 2010).

Forest and agrarian policy: engagement of farmers

Farmers should be actively involved in the agrarian reform policy making process so that their goals, objectives and socio-ecological environment are taken into account (Harrison, 2016; Isaacs et al., 2016; Larochelle et al., 2016), including being made aware of agroforestry options (Nsengiyumva et al., 2016; Mutandwa & Kanyarukiga, 2016; Nahayo et al., 2016). Farmers can begin to understand how important environmental benefits can be secured through agroforestry without compromising economic profits normally obtained from their farmlands. Procuring environmental benefits from agroforestry such as soil conservation, nutrient recycling, nonpoint pollution control, pest control, biodiversity conservation, water quality and many others requires long-term planning and goals (Nduwamungu, 2011). Given the fact that the majority of

Rwandan farmer households own less than 0.6 ha of farm land, it is logical to suggest that farmer priorities are oriented towards the immediate goals of food crop production and other strategies that support food production.

Forest policy can support adoption of agroforestry practices through strategies that integrate farm forestry in agricultural policies, promoting best management practices of trees and woodlots on farms, building capacity of farmers (Konig, 2007; Rushemuka et al., 2014), providing incentives for tree planting, and developing and disseminating farm forestry techniques in a unified extension system for all agroecological zones of the country (Ndayambaje et al., 2013). Of the numerous published agroforestry research activities conducted in Rwanda over the last 20 years, few have engaged with farmers through the use of participatory research methods (Bucagu et al., 2013).

Conclusion

Agroforestry is increasingly being recognized as an important adaptation and mitigation strategy against the negative effects of climate change. In particular, the use of multi-purpose trees has been promoted as an agroforestry practice that contributes to the improvement of soil fertility and food crop yields. While the importance of agroforestry is widely discussed, research on how agroforestry can be adopted successfully by reconciling socio-economic and environmental outcomes is still limited. In this study, I reviewed existing literature to examine opportunities for reconciling environmental and economic goals of agroforestry adoption. Historically, agroforestry has emphasized the plantation of woodlots on agricultural lands more than the association of trees and food crops. Furthermore, development and dissemination of agroforestry practices has typically not engaged the farmers themselves in a participatory process. Research on the contributions of various agroforestry practices to environmental integrity and crop yield improvement is lacking. Agrarian policies could make agroforestry adoption more effective by accommodating farmers' goals, objectives and socio-ecological environment and by involving farmers through demonstration plots to assess how agroforestry can successfully integrate economic and environmental outcomes.

There is a need for research to accurately assess the performance of different agroforestry practices in different contexts in improving soil fertility, supporting pollination processes, controlling soil erosion, abating pest incidence, controlling water quality and flow, while providing other socio-economic benefits such as fuel wood, fodder for livestock, building materials, and stakes for climbing beans. This research should be participatory by involving farmers themselves in order to subsequently facilitate the adoption and the dissemination of the technology.

To ensure that the full potential of agroforestry to provide environmental benefits, ecosystem services and food security is realized, there is a need for research to ensure that variation in farmer social, economic and environmental context is considered to improve uptake and adaptation. In this respect, studies to assess the relationship between tree species that farmers prefer and their environmental and economic function are needed to develop agroforestry practices tailored to farmers' economic needs and which also satisfy environmental parameters and anticipated outcomes. Agroforestry may be successful if factors that contributed to the slow adoption of tree planting on farms since the colonial era are considered seriously and if farmers' input in the choice of agroforestry practices and trees threes of their choice incorporated. Engagement of farmers requires active support from agricultural extension services.

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Chapter 3: Smallholder farmers perceptions of climate change and adaptation strategies in the northern highlands of Rwanda

Abstract

Smallholder farmers in poor countries generally rely heavily on agricultural production for their livelihoods, generally have the least capacity to adapt to climate change, and are expected to suffer the most from climate change and climate variability. Timing of crop planting, crop choice and agroforestry practices are adaptation strategies to reduce the impacts of climate change on smallholder farmers. Understanding local farmers' perceptions of climate change, willingness to adopt adaptation strategies and challenges to adaptation are fundamental to addressing issues of soil conservation and poverty reduction under environmental change. To develop appropriate policies and strategies for climate change adaptation in the agricultural sector, it will be crucial not only to understand changes in climate, but also to understand how they are perceived and adapted to by local residents, and how any adaptation strategies proposed are perceived by local farmers. The northern highlands region of Rwanda is one of the most climate-sensitive areas in the country due to dense smallholder agriculture landuse with limited agroforestry. This study explored farmers' perceptions of climate change and current adaptation strategies, and challenges and opportunities pertaining to the adoption of agroforestry as one of the adaptation option. Results of a survey conducted with 430 farmers within the northern highlands (Musanze District) of Rwanda between August and December 2015 indicate that most farmers perceived a shift in the onset of short rains and they have adapted planting timing accordingly. Analysis of rainfall data shows a recent increase in average monthly rainfall for the short rainy season as well. The results indicate that farmers perceived risks imposed by climate change on certain crops,

particularly maize and potatoes. However, farmers did not respond accordingly; their goal of increasing short-term financial profitability overwrote their willingness to adopt agricultural practices that sustain soil conservation. Regarding farmers' willingness to adopt agroforestry as a strategy for climate adaptation within their farmlands, a significant positive relationship was found between recognition of the importance of planting trees in association with crops, and age, level of education and income. In promoting awareness among famers about climate change adaptation strategies including agroforestry, results highlight the need to have farmers realize a greater longer term economic benefit from adopting the strategies over short term economic gain, to explore the potentials of farmer-to-farmer extension, using participatory approaches to generate solutions that are based on their experiences of climate change, and to improve the effectiveness of government-led extension to farmers.

Key words: Agroforestry, extension services, financial incentives, food security, short-term profitability, soil conservation, soil degradation

Introduction

Many scientists agree that developing countries, where agriculture is the main source of livelihood and where there is the least capacity to adapt and reduce risk, are expected to suffer the most from climate change and climate variability (IPCC, 2014; McBean & Ajibade, 2009; de-Graft Acquah & Onumah, 2011; Gbetibouo, 2009). Because agricultural production remains the main source of income for most rural communities, farmers' adaptation to climate change is critical (Adger et al., 2007). The term adaptation refers to "adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC 2001). Adaptation at the farm-level can involve two stages: perceiving the change in climate, and deciding whether to adapt or not; or which adaptation strategy to choose (Maddison, 2007). Farmers are believed to perceive recent climate changes based on their personal experience (Tessema et al., 2013) and some local farmers often have a very clear memory of years dominated by extreme weather events (e.g. Mertz et al., 2009; Manandhar et al., 2011; Tambo & Abdoulaye, 2013; Yaro, 2013). Such perceptions of strong recent climate stimuli can trigger short-term responses by farmers (Gbetibouo, 2009; Smith et al., 1996). However, it may not always be an easy exercise to put together an accurate mental picture of past climate trends since farmers' memories are usually focused on extreme weather events rather than general trends (Tambo & Abdoulaye, 2013). Thus, adaptation may be more likely based on responses to extreme events rather than slow, long term shifts in climate.

Farmers' responses to climate stimuli hinge not only on recently-experienced changes and impacts of climate but also on a complex interplay between social, economic and institutional factors (Bryan et al., 2009a; Maharjan et al., 2011; Maddison, 2007), including access to information (Hassan, Nhemachena, & others, 2008; Temesgen Tadesse Deressa, Hassan, Ringler, Alemu, & Yesuf, 2008) which can be acquired through formal education, the media and extension services. Access to agricultural extension services has been shown to have a significant impact on adaptation to climate change (Fosu-Mensah et al., 2012; Schuck, Nganje, & Yantio, 2002; Hassan et al., 2008; Maddison, 2007; Franz et al., 2010). Farmer-to-farmer extension services, coupled with government-led extension services, has been effective in adaptation given its contagious nature and trust among neighboring farmers (Kiptot et al., 2006; Davis et al., 2012). Inaccessibility of extension services by poor marginalized farmers including women, minorities, and people in very remote areas can even undermine effective adaptation to climate change (Davis et al., 2012; Anandajayasekeram et al., 2007).

Besides access to information and training, it has been argued that farmer financial capacity contributes substantially to climate change adaptation. Farmers with higher household income have been shown to be more likely to adopt new agricultural practices, given greater access to financial resources such as credits and subsidies (Franzel, 1999; Knowler and Bradshaw, 2007; Croppenstedt et al., 2003; Nhemachena and Hassan, 2007; Gandure et al., 2013; Deressa et al., 2011). However, in some countries such as Rwanda, where micro credit schemes are widespread and are believed to contribute to the efficiency of agricultural production, micro credit is virtually inaccessible to smallholder poor and uneducated farmers, and could threaten farmers' capacity to adapt their agricultural practices to climate change (Nabahungu & Visser, 2013; Ali et al., 2014; Musanze, 2013; Mutandwa & Kanyarukiga, 2016). Access to information and financial capacity may be an important enabling and empowering means to ensure economic profitability and sustainability of agricultural practices under climate change, especially when available to poor farmers with minimal formal education.

Another strategy proposed as an effective means to adapt to climate change involves agroforestry practices, which may not only contribute to soil fertility but also provide other benefits such as soil erosion control, stream bank stability, control of sedimentation and nutrient loading into streams (Atangana et al., 2014). The adoption of agroforestry among smallholder farmers is believed to depend largely on farmers' understanding of the importance of the practice, through extension services and farmer-to-farmer extension (Kiptot et al., 2006). In addition, adoption of agroforestry, like any other agricultural practice, hinges on a clear understanding of its economic profitability relative to the costs of implementation (McGinty et al., 2008).

Economic profitability is a major driver of climate adaptation among farmers particularly with respect to the choice of farming systems and crop choice (Chouinard et al., 2008; Musshoff & Hirschauer, 2008; Cary & Wilkinson, 1997). Economic profitability includes maximization of gross margin, and minimization of working capital, hired labor, management difficulties, and risk (Sheeder & Lynne, 2011). From a socio-psychological perspective, following the Theory of Planned Behavior (TPB), access to information and financial incentive are imbedded in what Läpple & Kelley (2013) is termed *belief-based measures* which influence the intentions to perform a behavior, innovative, adaptive agricultural practices in this case. Scholars of the Theory of Planned Behavior (TPB) such as Ajzen (1991, 1985, 1991) and Gellman & Turner (2013) suggest that perceptions drive willingness or reluctance to adopt any given behavior; that is, any given attitude or behavior will be influenced by the perception of expected benefit of the behavior or past experiences that justify a need to adopt a new behavior. TPB includes the possibility of heterogeneous decision structures among farmers who have different levels of environmental concerns, a component that falls under social norms (Läpple & Kelley, 2013).

While research on farmers' perceptions of climate change and adaptation abound in Africa, focus has been virtually restricted to dry regions and adaptation has focused on farmers' adaptation practices and challenges pertaining to adaptation (Bryan et al., 2013). Little has been done in humid regions such as the northern highlands of Rwanda, Uganda, and Congo (e,g. Diem et al., 2016; Osbahr et al., 2011). In addition, research on climate change perception has not looked at farmers' attitudes towards innovative agricultural practices for adaptation, factors influencing willingness to adopt certain behaviors, nor the opportunities and challenges that could be considered to facilitate the adoption of the practice.

In this study, I used survey data collected from smallholder farmers in the northern highlands of Rwanda to understand farmers' perceptions of climate change and decisions about adopting adaptation practices. I also analyzed rainfall data from the Kigali airport climate station to analyze seasonal variability in order to validate local perceptions of changes in seasonal rainfall variability. I hypothesized that (1) farmers' perceptions of seasonal variability are associated with residence time, household income, and level of education; (2) planting season is associated with the perception of variability of the onset of rainfall; (3) farmers choice of crops to plant are primarily driven by short-term profitability rather than sustainability of their farming activities; and (4) farmers' willingness to adopt agroforestry is associated with their residence time and education level rather than their level of income.

Methods

The research used qualitative and quantitative methods to gather primary data in 2015 from 430 smallholder farmers within the Upper Mukungwa Watershed. The goal of the research was to understand farmers' responses to climate stimuli especially with regard to the onset of rains and their attitudes about the adoption of agroforestry as a climate adaptive strategy. Understanding the relationship between farmers' perceptions of climate change and variability, and their decisions about planting timing and crop choices can help policy and decision makers design solutions that are tailored to smallholder farmers' needs for effective climate adaptation.

Study area.

The upper Mukungwa watershed (Figure 3-1) covers about 60% of the Musanze District land surface area, which is located in the northern highlands of Rwanda. The watershed lies in a region characterized by a bimodal rainfall pattern where rainfall seasons are significantly influenced by the Intertropical Conversion Zone which oscillates annually between the northern and southern tropics (McSweeney et al., 2010). The major rainy season is between February and June with a peak in April, and the minor rainy season is between September and December with a peak in November. The region experiences severe soil erosion and flooding due to steep slopes and episodes of high rainfall (Nahayo, Ekise, & Niyigena, 2013; Zimmerman et al., 2012; REMA, 2011; Musanze District, 2013; SEI, 2009).

Musanze has a landscape divided in two main areas: volcanic plains and the mountain range. The volcanic plains cover the central and north part of the district, including the Musanze, Muhoza, Muko, Kimonyi and Cyuve sectors; average altitude is 1,860 m. The mountain range is located in the southeast of the district, covering over a third of the total surface of the district, with an altitude range from 1,900 m to 2,000 m, covering the Muhoza, Cyuve, Gacaca, Rwaza, Gashaki, Remera and Nkotsi sectors (Rugazura & Murugesan, 2015).

The Musanze District is 76% agricultural lands. The study site lies on volcanic soil in an area characterized by a moderate and humid climate due to the high elevation and abundant rainfall, with an annual temperature and rainfall average of 16^{0} C and 1400mm, respectively (Musanze District, 2014). Over 90% of the population relies on subsistence agriculture for its economy. Potato is the major food and cash crop in the highland regions of Rwanda, followed by maize and beans. Wheat, peas, banana, and other vegetables and fruits are also cultivated (Muhinyuza et al., 2012). According to the National Institute of Statistics (NISR, 2012), females account for 54.1% of the Musanze population. The average household size is 4.8. Nearly 80% of the population is identified as non-poor, 14% as poor and 6% as extremely poor. The Ministry of Local Government uses the following definitions for each income category: extremely poor do not have a house or cannot pay rent, have a poor diet, and cannot get basic household tools and clothing; the poor include those who have their own houses or can afford to rent a house, can generally obtain food and can earn a wage from working; the non-poor include those who have at least one person in the family working in the government or the private sector; high income people are considered those who earn high incomes, own houses and can afford a luxurious lifestyle (MINALOC, 2015).

Agriculture is the main industry for 67% of the population aged 16 and above. The mean size of land cultivated per household is 0.5 ha; 87% of households cultivate under 0.9 ha of land (Musanze District, 2014), which is below the minimum household farm size of 0.9 ha required to conduct sustainable agriculture. The majority of females in Musanze district are small scale-farm workers (73%); small-scale farm workers among males account for 37%. Only 46% of agricultural households have access to chemical fertilizer. Figures about the rate of illiteracy were not available but 85% of individuals aged six and above have attended primary school.

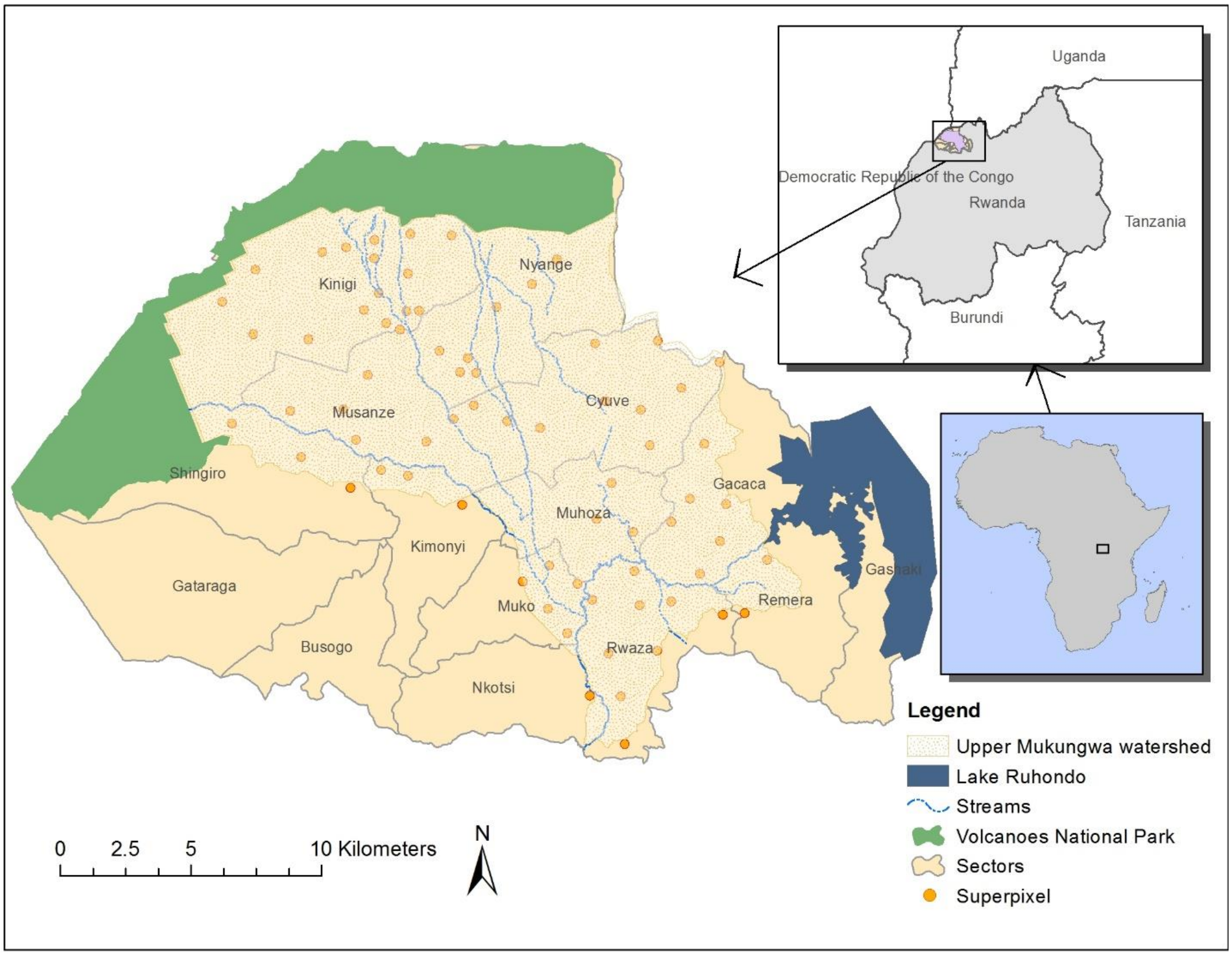

Figure 3-1. Upper Mukungwa Watershed in Rwanda with locations (superpixels) where household interviews were conducted

Household Climate Perceptions and Risks.

Household surveys were used to examine local farmers' perceptions of environmental change within the Upper Mukungwa watershed. The watershed (244 km^2) is predominantly agricultural besides a few grouped settlements known as "imidugudu" and the Musanze town. A set of 77 random geographic coordinates within this area was selected, and those points became the centers of 9-hectare areas (circles with radii of 170 m) termed ''superpixels'' (Hartter, 2009) (Fig. 1). Interview respondents were selected from within each superpixel. The number of respondents selected per superpixel was based on availability during the period of interviews for a given superpixel and at least one interview was conducted in each superpixel. Houses were selected based on proximity to the center of the superpixel. The closest house to the center was selected for the first interview, the next closest for the second interview, and so on. A full description of the geographic selection methodology can be found in Hartter, (2009). The survey was conducted between August and December 2015.

Interviews were conducted in person by myself with two field assistants, using Kinyarwanda, the local language. I spent one week training the field assistants before allowing them to collect data on their own, and after I trained them, each field assistant collected data interviewing a farmer and we would meet at the each of the interview to comment on how the interview went and discuss how the interviews could be improved. In the next step, field assistants started to collect data and I would check quality of the data every day for a couple weeks. After two weeks of data collection, field assistants continued to collect data and send in records every end of the week. I would then check data for errors, typos and missing data. Interview questions were structured and responses were then coded into categories during data analysis. Relationships between categorical responses and independent variables were examined with chi-square tests for independence (gender, location, wealth, newcomer status), while continuous variables were examined using binomial logistic regression (residence time, distance to park, stream and road, and respondent age).

Rainfall data analysis.

Long-term 24-hour rainfall data have been collected from the Kigali Airport Meteorological station since 1971. In order to compare recent and past trends in terms of onset of rains particularly for the short rainy season, I compared rainfall data between two time periods, the period of 1971-1998 and the period of 1999-2013. The later period was determined based on questions I asked to farmers about recent changes they have seen with respect to the onset of rains compared to more than ten years ago. With this information I found that this 15 year span of time can reasonably reflect the recent rainfall changes experienced by farmers. I focused only on the months of August and September for this analysis because September has been the traditional date that farmers use to start planting. I assigned an index to each month (August and September) depending on the number of rainy days from the first day of rain in that month to the last (thus for August there are 31 possible days for rain and a possible index of 31, and September has 30 possible days for rain); a day without rain was scored '0' and a day with rain was scored '1' and these scores were summed in each month to obtain the Index. This was done for both months across each year of the two periods, yielding an index of rain based on number of rain days for August and September in each year of the time period. I then averaged the indices assigned to days of rain for each month across all years of each of both periods.

A t-test was performed to compare means of indices between the two periods of 1971-1998 and 1999-2013 for the months of August and September respectively. Results were also plotted in a graph to show changes in rain index peaks between the two periods.

Results

General farmer characteristics and agricultural systems within the study site.

A total of 70 superpixels were sampled and 430 farmers were interviewed within those superpixels. More females than males were interviewed. A large proportion of interviewed farmers were illiterate, owned small farmlands and were poor (Table 3-1).

Table 3-1

Population Statistics of Respondents in the Upper Mukungwa Watershed, Rwanda

Population characteristics	Total
Sample size	430
Average Household size	4.6
Male (%)	43
Female (%)	57
Illiterate	50
Completed primary education (%)	39
Completed secondary education (%)	7
Higher education (%)	4
Mean experience	29
Average age	44
Farm size between 0 and 0.5 hectares (%)	51

Farm size between 0.5 and 1 hectare (%)	40
Farm size between 1 and 5 hectares (%)	9
Very low income (%)	27
Low income (%)	39
Medium income (%)	33
High income (%)	1

Farmers' perceptions of climate.

Farmers were asked to describe what they could say about current climate. The most common response from the respondents was that they were experiencing a change in weather and in onset and duration of rains in rainy seasons, and the second most frequent response was that they did not know anything to say about the climate (Figure 3-2).

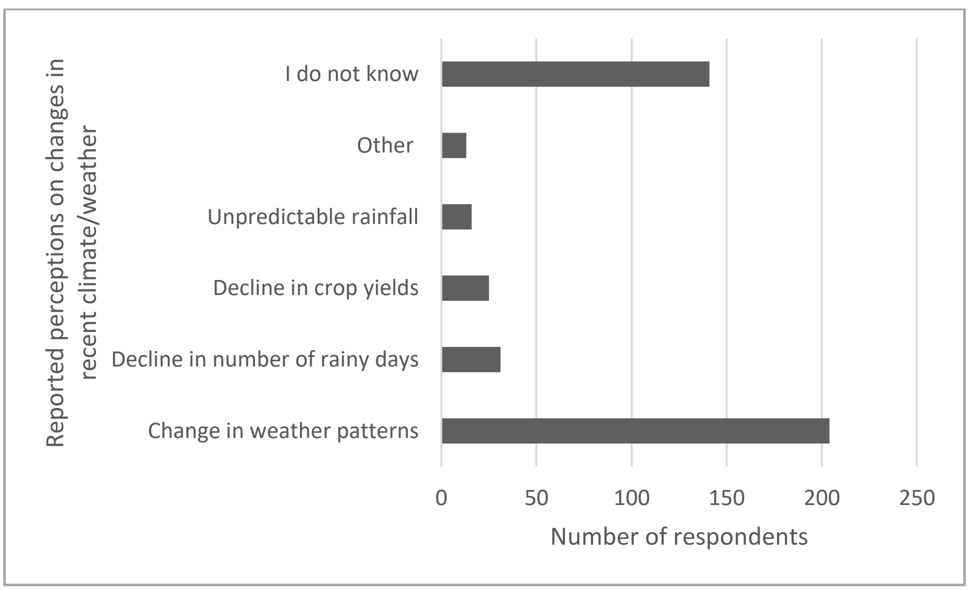

Figure 3-2. Perceptions of changes in current climate/weather/seasons change by farmers in the Upper Mukungwa watershed, Rwanda

Timing of onset and cessation of rainy seasons.

To further investigate respondents' perceptions of climate change/climate variability, I asked questions about the timing of onset and cessation of rainy seasons. Answers to these questions helped understand whether farmers' perceptions about perceived changes in the onset and cessation of seasons drive their crop planting timing.

When respondents were asked if they felt that the short rainy season (typically from September-December) has been starting: earlier, about the same time, later, or different each year in recent years compared to 10 years ago or more, the majority of participants reported that the onset of rains comes earlier and another large number of respondents reported that it is variable from year to year (Figure 3-3). Only a small number or respondents said the onset has not changed (2%) or comes later (8%). Respondents were also asked about the end of the long rainy season and most of respondents reported that the season ends earlier.

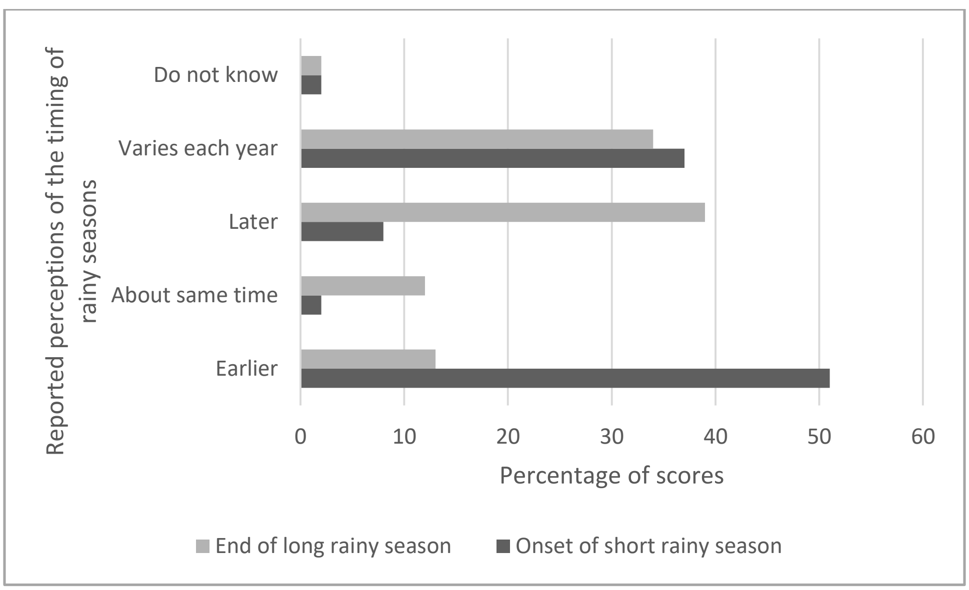

Figure 3-3. Farmers' perceptions of the timing of rainy seasons in northern Rwanda, including perceptions of the cessation of the long rainy season and the onset of the short rainy season.

Logistic regression test results (Table 3-2) suggest that farmers with relatively higher income are more likely to feel that the short rainy season (September-November) begins earlier or is now more variable from year to year. Likewise, they are more likely to feel that the cessation of the long rainy season comes late or varies from year to year. These perceptions were not associated with gender or age. However, there was a significant association of those perceptions and the length of residency of farmers in the area. Finally, there was a positive relationship between farmers' perceptions that the onset of the short rainy season comes earlier or later and the status of being literate. Likewise, perceptions that the cessation of the long rainy season comes later or varies from year to year are also associated with the state of being literate.

Table 3-2

Perceptions of Local Households about Changes in Onset and Cessation of Rainy Season
(Bolded Numbers Indicate Significance of Dependency)

		Onset of short rainy season		**Cessation of long rainy season**			
	N	Earlier	Variable	Early	Late	Same	Variable
Total	430	51%	37%				
Gender							
Male (code = 1)	184	46%	40%	11%	36%	12%	35%
Female (code = 0)	246	55%	35%	15%	41%	13%	34%
p-value		0.064	0.269	0.250	0.424	0.883	0.759
Wealth							

Very poor	115	67%	19%	11%	61%	13%	16%
poor	166	60%	25%	14%	46%	14%	23%
Medium income	144	29%	65%	13%	13%	11%	62%
Wealthy	5	20%	60%	20%	40%	0%	40%
P-value		**< 0.001**	**< 0.001**	0.753	**< 0.001**	0.635	**< 0.001**
Education							
Illiterate	216	57%	25%	13%	47%	14%	43%
literate	214	44%	49%	14%	30%	11%	46%
p-value		**0.007**	**< 0.001**	0.803	**< 0.001**	0.322	**< 0.001**
Age							
p-value		**0.076**	0.240	0.452	0.387	0.405	0.758
Residency							
p-value		**< 0.001**	**< 0.001**	0.496	0.10	**0.001**	**< 0.001**

Timing of crop planting.

Farmers were asked if in recent times compared to 10 years ago, they plant their crops earlier, later, same time each year, or if the timing for crop planting varies from year to year. The majority of respondents reported that they plant crops earlier than 10 years ago. There was also a substantial number of respondents who reported that the timing for crop planting varies from year to year (Figure 3-4).

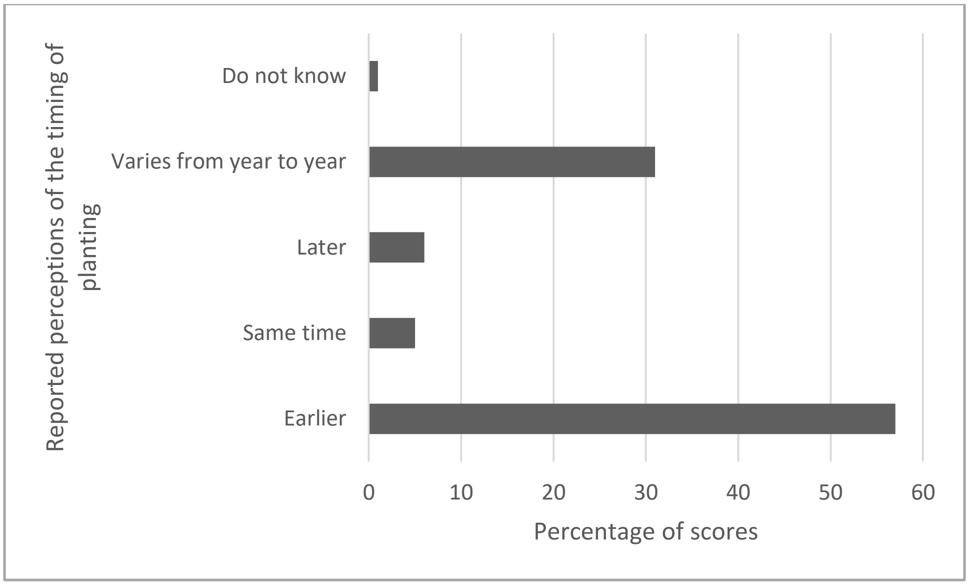

Figure 3-4. Farmers' responses about their perceptions of the timing of crop planting

Results from the survey data also show that farmers who perceive that the onset of the short rainy season comes earlier are significantly more likely to plant their crops later (Table 3-3). Those respondents who believe that the onset of short rains is variable from year to year are significantly more likely to plant their crops at variable times (Table 3-3).

Table 3-3

Relationship between Perceptions of the Timing of the Onset of the Short Rainy Season and Timing for Crop Planting

	Onset of planting			
	Earlier	Later	Same	Varies each year
Onset of short rain season				
Earlier	18%	**56%**	15%	8%
p-value	0.003	**< 0.001**	0.040	< 0.001

Variable	5%	11%	4%	**79%**
p-value	< 0.001	< 0.001	0.001	**< 0.001**

Rainfall seasonal variability

I analyzed average number of rainy days between the periods 1971-1998 and the period 1999-2013 to see if there was a significant difference in the variability of number of rainy days and if the short rains comes earlier in recent years compared to more than fifteen years ago. First I assigned number 1 to each rainy day, then I averaged the numbers for each day across each of the two periods (1971-1998 and 1999-2013 for the months of August and September respectively.

Results show graphically higher peaks over average rainy days in August (Figure 3-5) and relatively lower peaks in September in recent years compared to more than 15 years ago (Figure 6). However, a statistically significant difference is for the month of September (($t\ (56) = 2.003$, $p = 0.018$).

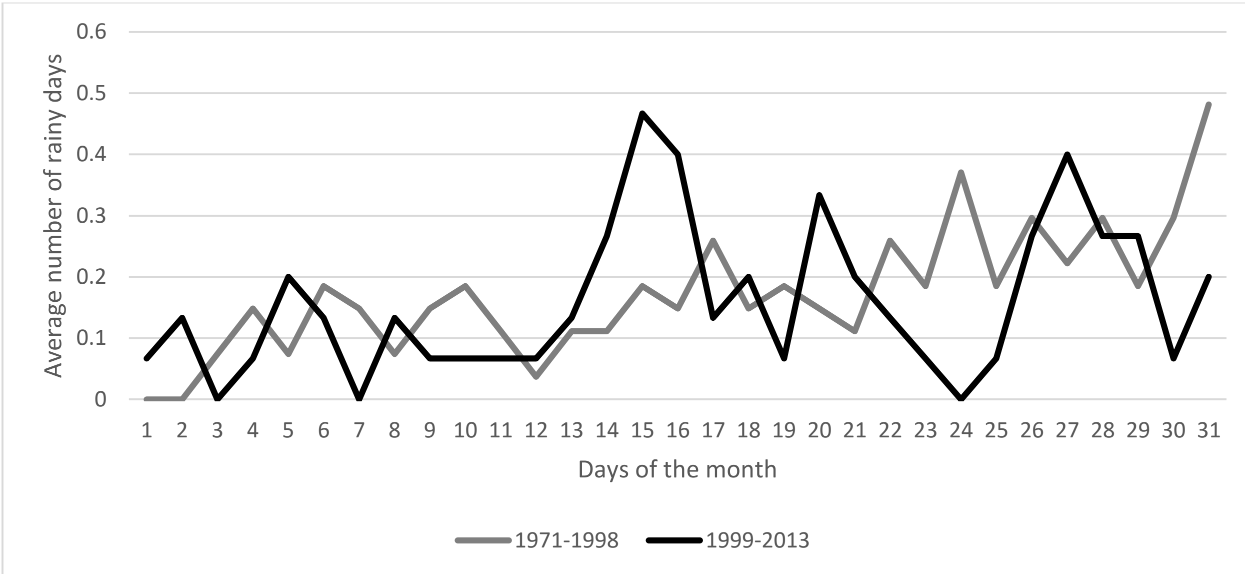

Figure 3-5. Average number of days of rain for the period 1971-1998 and 1999-2013 for the month of August

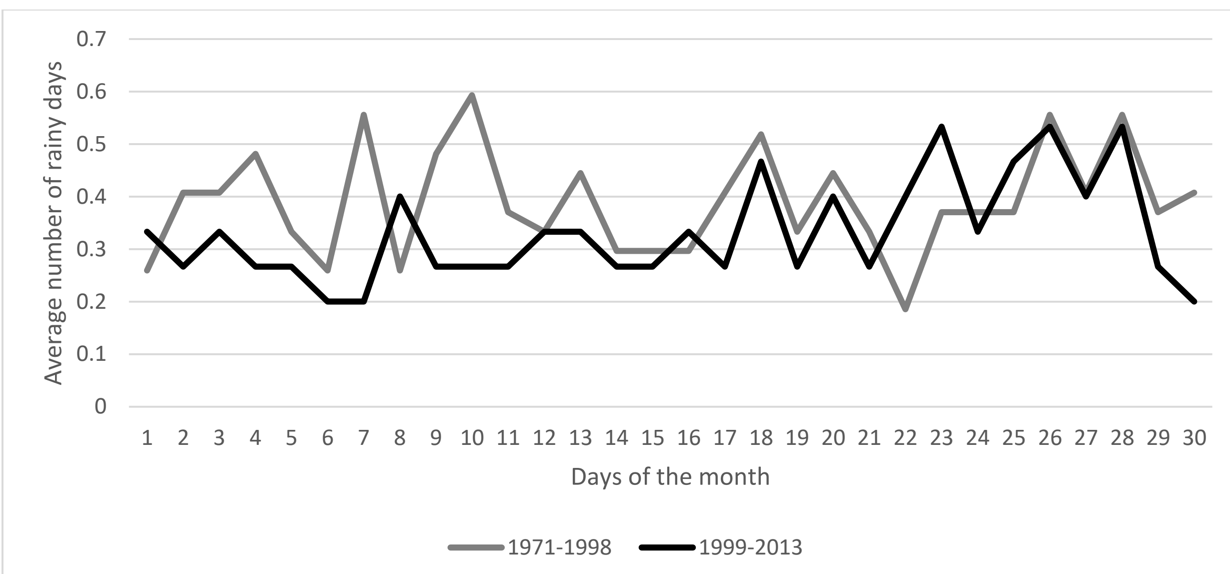

Figure 3-6. Average number of days of rain for the period 1971-1998 and 1999-2013 for the month of September

I analyzed 24-hour rainfall data from 1971-2013 using a t-test to determine if there was a significant difference in the variability of average daily rainfall for the months of August right after the dry season ends and September when the short rains typically start. I compared recent years (1999-2013) with previous years (1971-1998) by looking at cumulative daily rainfall starting from the first day of August (considered as day 1) to the last day of September (considered day 61) (Figure 3-7). The crop planting in the study area normally occurs during this period. The results were compared to what respondents reported about the onset of short rains. Results from a t-test revealed that there was no significant difference in the cumulative rainfall from beginning of August to end of September, between the periods 1999-2013 and 1971-1998 ($t(119) = 1.98$, $p = .393$).

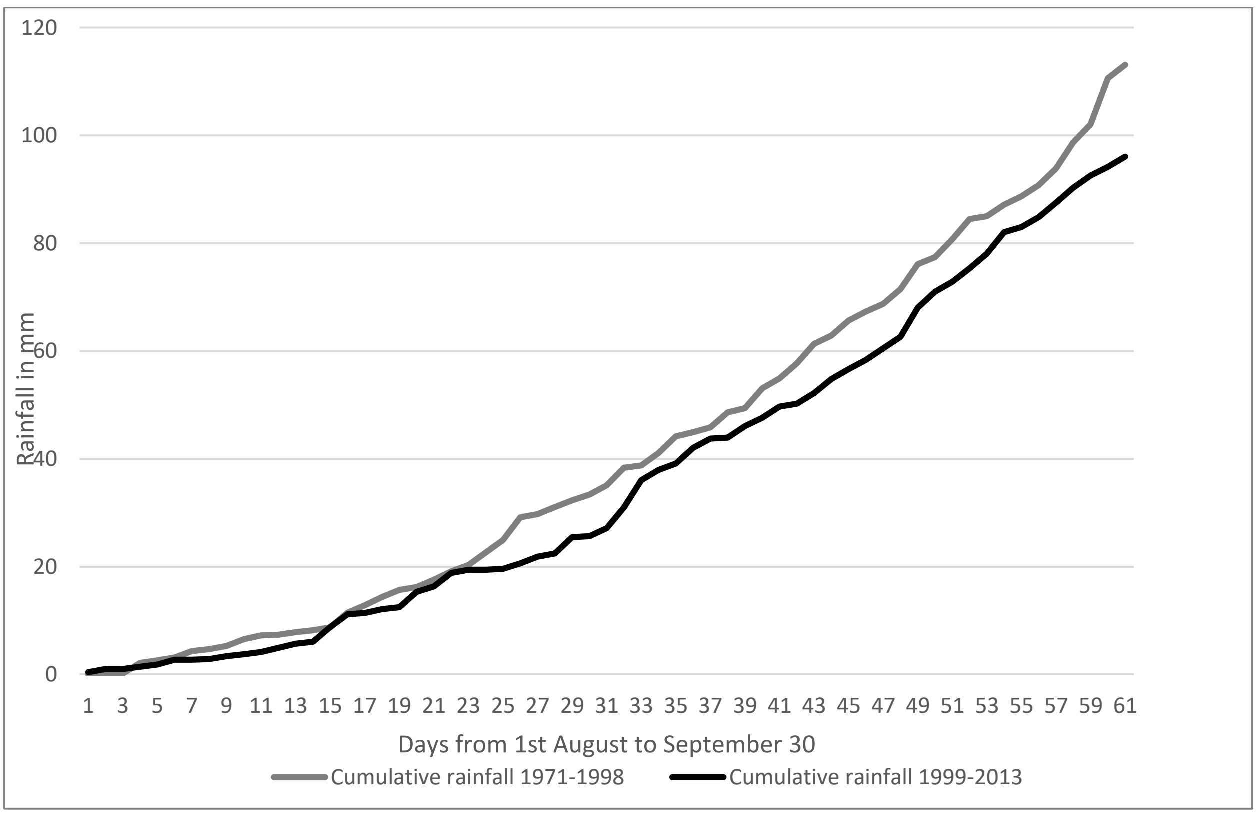

Figure 3-7. Cumulative daily rainfall averages for Kigali Airport meteorological station, Rwanda

I further examined seasonal distribution of monthly average rainfall for the periods 1999-2013 and 1971-1998. For both periods, April and November correspond to peak rainfall months. A t-test shows a significant difference in monthly average rainfall between the two rainfall period in April (t (29) = 2.011, p = .05), but there was no significant difference for the month of November between both periods (t (29) = -0.183, p = 0.42). This suggests a significant decline in the rainfall peak of April during the long rain season in the period 1999-2013 compared to 1971-1998 period (Figure 8). There was no significant difference between October average rainfall between both periods (t (30) = 1.69, p = 0.11). The month of September does not show any statistical difference either (t (29) = 0.81, p = 0.21). There was no significant difference in rainfall variability between the two periods (t(22) = 2.074 , p = .79), indicating there is not sufficient evidence to warrant the claim that rainfall for the period 1971-1998 was higher on average than rainfall of the period 1999-2013.

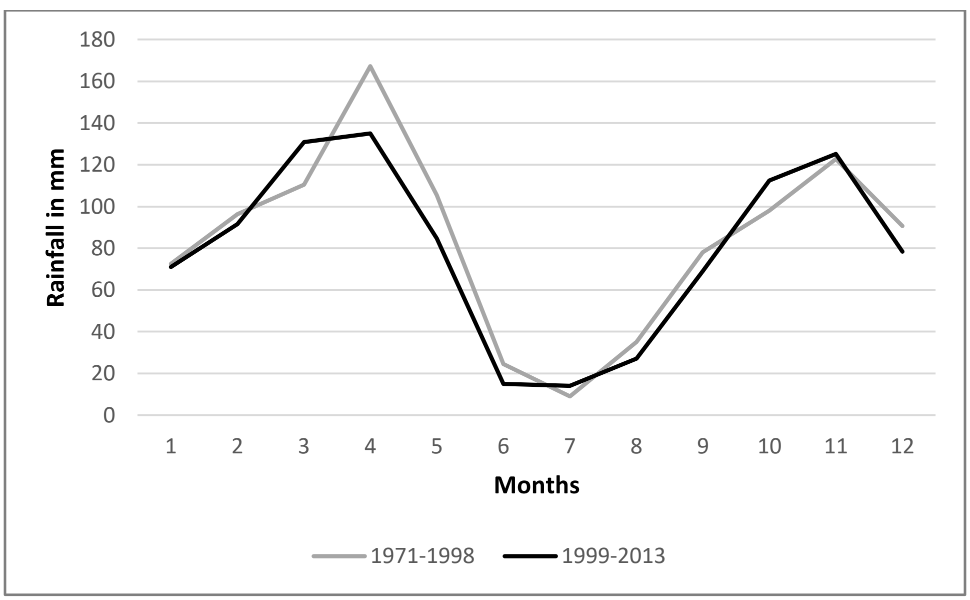

Figure 3-8. Monthly average rainfall at Kigali Airport meteorological station, Rwanda. Numbers 1 to 12 correspond to the months of a year.

Perception of climate risks.

Farmers were asked to rate current climate-related issues based on the level of adverse impacts of their households. Farmers in the study area reported climate-related issues that they experience and they ranked them based on the severity in terms of the extent to which their household is affected. Flooding, sediment accumulation, stream bank erosion, soil erosion and water pollution were identified and ranked (Figure 3-9). Soil erosion was reported to be the most serious risk, followed by sediment accumulation and stream bank erosion.

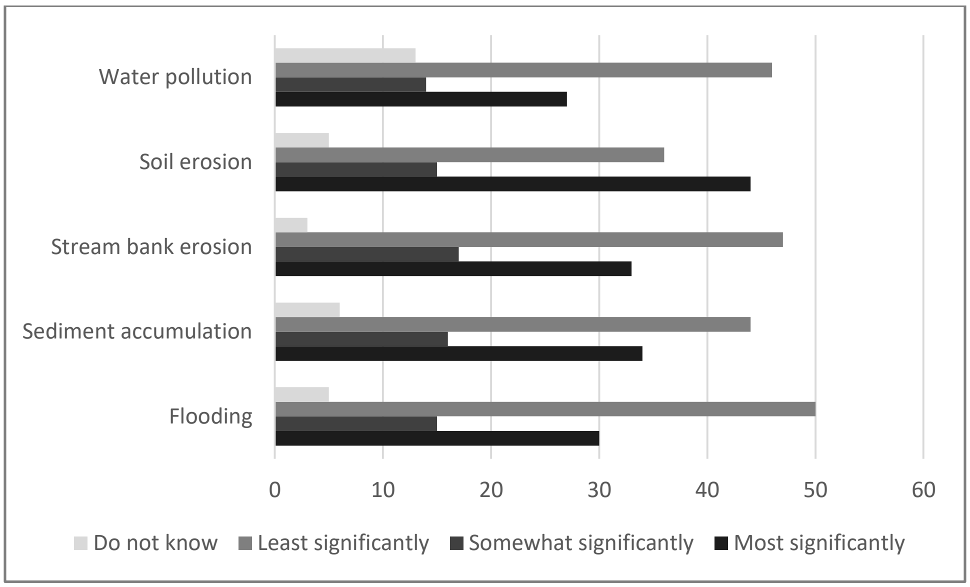

Figure 3-9. Rating of climate risks considered to be of significant concern among farmers in the study area

A multinomial logistic regression was used to ascertain a relationship between climate change related issues (independent variables) that farmers believe affect their households and respondents characteristics (dependent variables) including gender, education, farm size, income, residency length and proximity of respondents' household to streams and the Volcanoes National Park (VNP), and distance of farmland to streams (Table 3-4).

Table 3-4

Relationship Between Perceived Climate-related Issues Believed by Farmers to be of Concern and Socio-economic Factors (Significant relationships are highlighted in bold).

	Total	Flooding			Sediments			Stream. Bank erosion			Soil erosion			Water pollution		
		0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Gender																
Total	430	23	127	63	24	148	70	22	140	72	23	188	66	54	117	60
Female	246	56.5%	49.6%	42,9%	54,2%	49.3%	58.6%	54.5%	52.1%	56.9%	56.5%	52.7%	52.6%	57.4%	53%	60%
Male	184	43.5%	50.4%	57.1%	45.8%	50.7%	41.4%	45.5%	47.9%	43.1%	43.5%	47.3%	47.4%	42.6%	47%	40%
p-value		.372	**.003**	**.001**	.387	**.010**	.487	.544	.097	.526	.567	.062	.472	.945	.315	.868
Education																
Total	430	23	127	63	24	148	70	22	140	72	23	188	66	54	117	60
Illiterate	216	43,5%	41.7%	44.4%	41.7%	37.8%	51.4%	45.5%	34.3%	55.6%	47.8%	40,4%	56.1%	51.9%	37.6%	46.7%
Literate	214	56.5%	58.3%	55.6%	58.3%	62.2%	48.6%	54.5%	65.7%	44.4%	52.2%	59.6%	43.9%	48.1%	62.4%	53.3%
p-value		.199	**.005**	.066	.081	**.000**	.183	.187	**.000**	.493	.267	**.000**	.574	.397	**.000**	.114
Wealth																
Total		23	127	63	24	148	70	22	140	72	23	188	66	54	117	60

Very poor	115	30.4%	18.9	20.6	29.2%	18.9 %	27.1%	27.3%	14.3%	47.2%	30.4%	18.1%	34.8%	31.5%	17.1 %	21.7 %
poor	166	43.5%	30.7%	38.1%	45.8%	20.9 %	40.1%	45.5%	23.6%	34.7%	47.8%	27.7%	40.9%	46.3%	26.5 %	25.0 %
Medium income	149	26.1%	50.4%	41.3%	25%	60.1 %	32.9%	27.3%	62.1%	18.1%	21.7%	54.3%	24.2%	22.2%	56.4 %	53.3 %
p-value	Income 1	.813	**.000**	.011	.332	**.000**	**.023**	.688	**.000**	.063	.594	.000	.443	.704	**.000**	**.000**
	Income 2	.925	**.000**	.053	.339	**.000**	**.007**	.568	**.000**	.661	.627	.000	.158	.695	**.000**	**.000**
Residency																
p-value		.074	.224	.156	.294	.000	.960	.477	.005	.391	.958	.001	.713	.198	.201	.513
Age																
p-value		.083	**.024**	.985	.068	.061	.0.46	.083	.288	**.023**	.460	.144	.619	.090	.186	**.018**
Farm size																
p-value		**.037**	**.000**	.143	**.001**	**.000**	**.015**	**.006**	**.000**	.672	**.009**	**.000**	.779	**.043**	**.007**	**.006**
Proximity to stream																
p-value		**.012**	**.021**	.517	**.023**	**.000**	**.021**	**.018**	**.001**	**.022**	**.040**	**.000**	.204	.421	**.002**	**.006**
Proximity to VNP																
p-value		**.007**	.555	**.001**	**.024**	.164	**.019**	.161	.215	.123	**.037**	.699	.145	**.000**	.179	.955
Closeness of farmland to streams																
p-value		.395	**.000**	.072	.058	**.000**	.062	.069	**.000**	.060	.060	**.000**	.078	.548	**.000**	.552

Results show a significant association between farmers' beliefs that flooding, sediment accumulation, stream bank erosion, soil erosion and water pollution represent serious risks for households and variables including education, income, farm size, closeness of a household from a nearby stream, closeness of any of the respondent's farm plot to a stream (Table 3-4). Results in the table suggest that relatively high-income level and educated farmers are more likely to believe that flooding, sedimentation, stream bank erosion, and soil erosion are challenges to agricultural production than poor, illiterate farmers. However, farmers whose farms are in proximity to streams and the Volcanoes National Park are more likely to believe that those environmental issues are of concern than farmers who do not own farms in this proximity.

Farmers' perceptions of recent increase in the cultivation of certain crops and rise in concerns about climate change risks.

First, I asked farmers about which crop types have increased or decreased in cultivation over recent years compared to ten years ago. A great majority of farmers (82% and 75% of respondents respectively) strongly agreed that corn and bean cultivation has increased substantially. Besides corn and beans, Irish potatoes was reported to have increased in cultivation over recent years (49% of respondents). Secondly, farmers were asked about which type of crops are the most susceptible to the effect of soil erosion. This is a very relevant question because the Musanze District administration recognizes soil erosion as one of major challenges to agricultural production (Musanze, 2013). Results show that the majority of respondents believe that beans, corn and Irish potatoes are the most vulnerable to soil erosion (Figure 3-10).

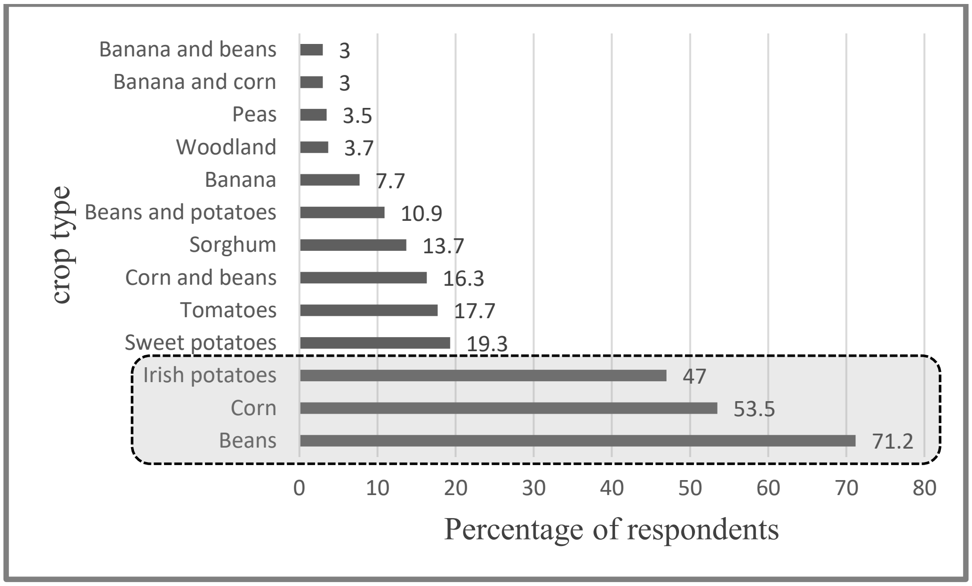

Figure 3-10. Crop susceptibility to damage due to soil erosion, based on farmers' perception

To understand what motivates farmers to plant crops most vulnerable to soil erosion, I asked farmers to indicate their level of agreement (strongly agree, somewhat agree, disagree) on factors that may underpin their choice. Results reveal a vast majority of farmers reported that their choice is dictated either by crop rotation cycles (the growing of different crops in succession on a piece of land), economic profitability, family nutritional needs or recommendations from the government (Figure 3-11).

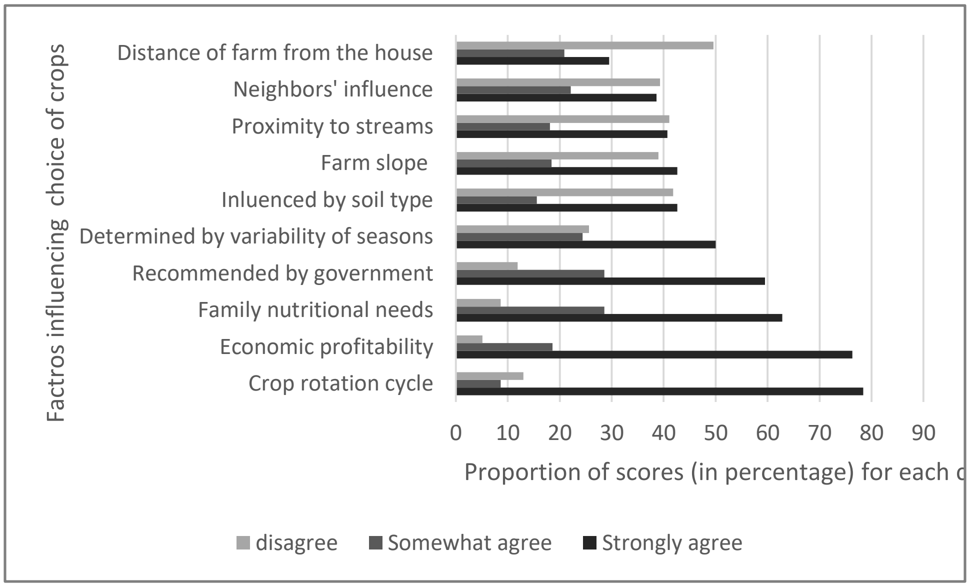

Figure 3-11. Rating of factors that drive farmers' choice of crops to plant

Attitudes towards the adoption of agroforestry.

Recent literature suggests agroforestry can serve as an effective strategy to limit soil erosion from happening and to contribute to soil fertility recovery while providing other ecosystem services that support farming and farmers' livelihoods (Atangana et al., 2014a; Mbow et al., 2014). I gauged farmers' interest and willingness to adopt agroforestry after I presented to them the benefits of interplanting crops with trees. Results show that a majority of respondents (64% of farmers) expressed willingness to adopt agroforestry practices. A logistic regression model was used to assess the relationship between willingness to adopt agroforestry and socio-demographic factors as well as the perception of soil erosion as a major problem. Positive attitudes towards agroforestry were significantly negatively associated with the length of respondents' residence ($\chi2 = 4.115$, df = 1, $p = 0.043$); that is, recently established farmers compared to farmers who have been farming the land for a long time are more likely to adopt agroforestry. Similarly, there was also a positive relationship with literacy category; literate farmers had significantly positive attitudes about the adoption of agroforestry in comparison to illiterate farmers ($\chi2 = 7.946$, df = 1, p = 0.005). The positive attitude towards agroforestry was also positively associated with the income level of respondents ($\chi2 = 8.086$, df = 1, p < 0.004). However, no significant association was found with soil erosion as a problem ($\chi2 = .207$, df = 1, p = .649).

Perceived Challenges to the adoption of agroforestry.

Six challenges to the adoption of agroforestry were identified by the majority of respondents and can be summarized into two major categories: financial and technological challenges (Figure 3-12). Virtually all respondents indicated that the fact that agroforestry does not generate immediate benefits could be an impediment to its adoption.

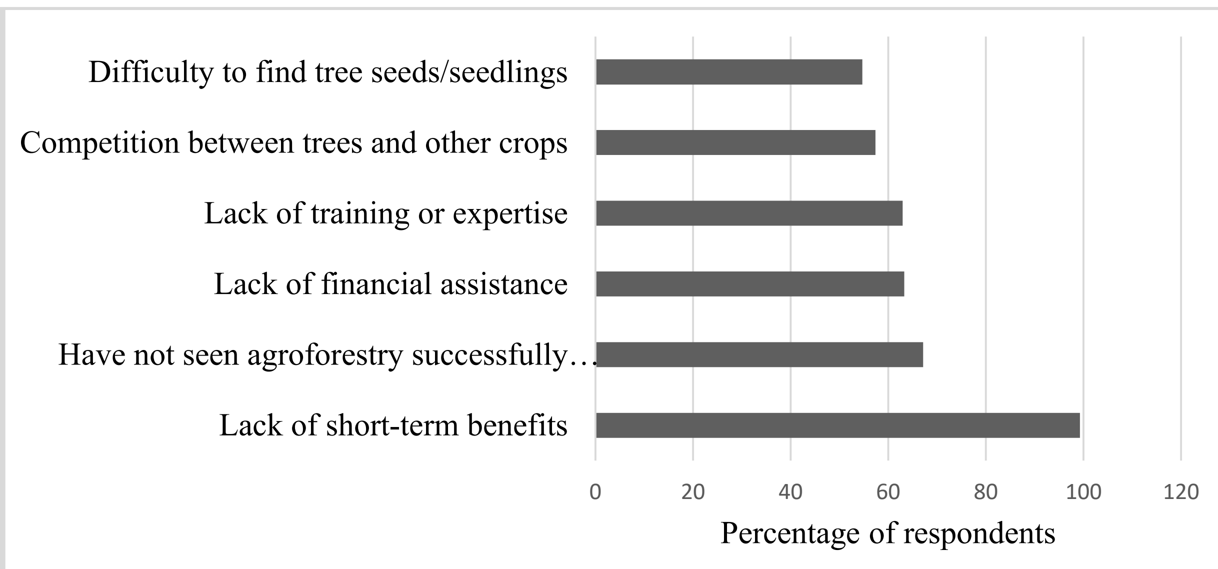

Figure 3-12. Rating of major challenges inherent to potential adoption of agroforestry by farmers in the Upper Mukungwa Watershed, Rwanda

Discussion

Awareness of change of onset of short rainy seasons.

The vast majority of farmers in this study believe that the onset of the short rainy season comes earlier in recent years compared to more than ten years ago. Analysis of average rainy days between the periods 1971-1998 and 1999-2013 shows a significant shift in the average of rainy days for the month of September with relatively lower peaks and higher peaks in August compared to the period 1971-1998. A recent study of onset, cessation and length of growing season in western Kenya by Mugalavai et al. (2008) showed no shift in seasons for the past 15-34 years. Other studies on East Africa, including Rwanda, have predicted an increase of precipitations during the short rain season. Mean precipitation in Rwanda is projected to increase by more than 10% by year 2100 (Shongwe et al., 2008; Black, 2005). During the season from mid-September to December, humidity in Rwanda comes from air masses humidified by the Indian Ocean and Lake Victoria (NAPA-RWANDA, 2006). This increase could be explained by the Indian Ocean Dipole (IOD) (Behera et al., 2005) but it does not seem to affect average monthly rainfall in Rwanda. Studies on climate change in Rwanda are needed to elucidate the effect of an increase in humid air masses from the Indian Ocean on rainfall intensity, distribution and onset of seasons in order to support climate adaptation strategies.

Timing of planting and onset of short rains.

Regarding the question of whether the planting season is associated with the perception of variability of the onset of rainfall, most of farmers who claimed that the onset of short rains comes earlier reported that they tend to plant crops relatively later than they did 10 years ago. However, most farmers, including those who did not report that short rains come earlier, claimed to plant crops earlier. This may suggest that recent increase in short rains provides the soil with enough moisture and farmers can grow their crops earlier, However, given rainfall variability when considering each year individually, it is possible that some farmers wait until other farmers have planted their crops so that they can plant their own, or there might be other factors such as lack of input such as fertilizers, pesticides and labor.

Crop plant choice and climate adaptation.

The main goal of farmers and what generally drives their practice, according to the findings of this study, is to increase short-term financial profitability of their agricultural practices. Financial profitability has been suggested to be a major driver of climate adaptation among farmers particularly with respect to the choice of farming systems and crop choice (Chouinard et al., 2008; Musshoff & Hirschauer, 2008; Cary & Wilkinson, 1997). Economic profitability includes maximization of net profit with minimum risks (Sheeder & Lynne, 2011). Results of this study corroborate previous studies that farmers tend to subscribe to short term financial benefits and are reluctant to buy into long-term agricultural schemes that represent environmental benefits and effective soil conservation (Dale & Polasky, 2007; Karali et al., 2013). Interestingly, these short term financial benefits can have additional long term costs: as the results suggest, increased use of synthetic fertilizers is associated with increased cultivation of Irish potatoes and corn, which have become the main goal for farmers as part of their adaptation strategy. Soil loss following soil erosion is generally more pronounced in corn and potato crops planted in pure stands than in other crops commonly found cultivated in Rwanda (e.g. Clay and Lewis, 1990).

Reconciliation of climate-sensitive crops and agroforestry.

Most of farmers in this study reported that they are willing to adopt agroforestry. However, they also reported that successful adoption depends on financial and technological capacity. Along the same lines, it appears that the adoption of agroforestry, which is a long-term commitment, requires not only the understanding of its long-term benefits but also and most importantly the "know how" or technological capacity required for effective implementation of agroforestry that generates longer economic benefits that outweigh some short term reduction of current benefits (Nhemachena & Hassan, 2007). The results from this study also suggest that farmers with relatively higher income are more likely to adopt agroforestry. This seems to make sense in a country like Rwanda where virtually all farmers rely on subsistence agriculture with an average farm holding of 0.76 ha (Booth & Golooba-Mutebi, 2012) and an area of about 0.45 ha in the Musanze District, generally split up into fragments (Figure 10). The mean size of household in Musanze is 4.8 (National Institute of statistics of Rwanda, 2012). In this situation, smallholder farmers attempt to maximize the short term output from the plots. They plant potatoes which grow fast in all seasons and provide income for families. Beans also provide very good income and are the main source of protein for most smallholder farmers. Recent agricultural reforms in Rwanda (Pritchard, 2013) have yielded satisfactory results economically but may contribute to soil degradation and pollution through nutrients loads into streams (Wali et al., 2011; Huggins, 2009). From the farmers' perspective, food crop production is a priority. Farmers understand that agroforestry can contribute to protecting crops against the impact of climate change while providing other benefits they also need either for food production or their livelihoods such as fodder for animals and spikes for climbing beans. For this reason, a reconciliation of food crop cultivation and agroforestry is possible. This reconciliation would also help farmers cultivate on unfavorable hill slopes and hill tops as shown for example in Figure 3-13.

Figure 3-13. Agricultural management in the Musanze district, northern Rwanda

Farmers' willingness to adopt agroforestry was associated with the level of education, literate farmers being more willing to adopt the practice than illiterate ones. Studies from Ethiopia and South Africa (Bryan et al., 2009b) and in many other sub-Saharan countries (Hassan et al., 2008) show that farmers are more likely to adapt to climate change if they have access to extension, credit, and land. Extension services and information on climate change were found to facilitate adaptation among the poorest farmers (Hassan et al., 2008; Bryan et al., 2009b).

In Rwanda however, the problem does not seem to be related to the presence of extension services but rather to the inadequacy of those services as noted by Stainback, Masozera, Mukuralinda, & Dwivedi (2011) and Stainback et al. (2011). This gap might also be supported by the finding that about 63% respondents in this study claimed that lack of training and expertise is one of the major challenges pertaining to the adoption of agroforestry. Extension services can play a key role in disseminating skills and technology needed by smallholder farmers for effective adoption of agroforestry and by capitalizing on farmers' knowledge. Unfortunately, as pointed out by Ansoms (2010), extension services often serve merely as the implementers of the government's agricultural agenda without considering farmers' views. In anecdotal discussions during this study, I learned that extension services often focus on implementation of governmental agricultural policy and have less time to spend with farmers. Furthermore, as argued by Twomlow et al. (2008), among African extension services, the understanding of climate processes, driving forces, and meaningful coping and adaptive strategies remains insufficient. Therefore, while extension officers may tell farmers when it is time for planting specific crops, extension service support to farmers in terms of helping them understand climate change and how to cope in the long term can be limited.

Previous studies have demonstrated that farmers adopt innovations, agroforestry in this particular case, if they not only have required skills and knowledge pertaining to the designing, planning and implementation of such innovations among other things but also if they are involved in the process of planning, implementing and evaluating innovations (Mccann et al., 1997;Wennink et al., 2006). Furthermore, smallholder farmers are an important group of actors that need to be considered in strategies concerning sustainable land use and the restoration of degraded lands (Montagnini, Francesconi, & Rossi, 2011) because of their knowledge of the landscape in which they live (McCall & Minang, 2005). Therefore, extension services should work hand-in-hand with farmers. Innovations are more likely to be adopted when they have a high 'relative advantage' (perceived superiority to the idea or practice that it supersedes). When they are readily easy to test and learn about before adoption (Pannell & Vanclay, 2011) and economically profitable as previous studies have indicated (Drechsel, Steiner, & Hagedorn, 1996), farmers may be reluctant to endorse the idea of agroforestry as long as they have never seen successful cases of agroforestry in their agro-ecological zone.

Farmers' income level has been highlighted by a number of scientists as one of the major drivers of farmers' adoption of any given adaptation measure. Findings from this study suggest that about 91% of interviewed farmers own less than 1 hectare of total farmland per household and farming was indicated to be their main source of income. I found that the farm size per household seems to be an indicator of the household income. This finding corroborates other scientists' claims that farmers with higher household income are more likely to adopt new agricultural practices, given greater access to information and financial resources (Franzel, 1999; Knowler and Bradshaw, 2007; Croppenstedt et al., 2003; Nhemachena and Hassan, 2007; Deressa et al., 2009; Asfaw et al., 2011; Bryan et al., 2009a). A study conducted in South Africa to gauge farmers' perception of and adaptation to climate change revealed that although a majority of farmers were aware of climate change, a relatively small proportion adapted to climate change with lack of access to credit as the major inhibitor of adaptation (Gbetibouo, 2009).

Maddison (2007) suggested that some farmers perceive climate change but fail to adapt due lack of incentives or assistance to do what is in their own best longer term interests. These findings corroborate what I found in this study and are similar to the findings of other studies where financial and technological factors have been highlighted as the major drivers of effective adaptation of agricultural practices that provide long-term benefits (Hassan et al., 2008; Deressa et al., 2008) Nhemachena & Hassan, 2007; Hisali et al., 2011; Sanchez, 2002). I argue that incentives would be more effective if they could maintain farmers' current agricultural income level until agroforestry can start generating significant returns. This is a model used in the Green Belt Movement in which farmers received incentives during the initial tree planting phase so that returns from their farmlands could be maintained until trees could begin to provide benefits (Maathai, 2004). Financial incentives should also be supplemented by effective support from extension services through experimental plots where farmers could work together with extension services to test the performance of agroforestry within their own plots. While micro-credits schemes in Rwanda are widespread and are believed to contribute to the efficiency of agricultural production, credit is virtually inaccessible to smallholder poor and uneducated farmers (Nabahungu & Visser, 2013; Ali et al., 2014; Musanze, 2013; Mutandwa & Kanyarukiga, 2016). Lack of subsidies in terms of seeds, seedlings and fertilizers can thus deter farmers' willingness to adopt agroforestry.

In Rwanda, farmers' awareness and adaptation to climate change appears to be strongly influenced by policies such as the introduction of new corn, bean, and Irish potato varieties associated with increased use of synthetic fertilizers and pesticides, and the deployment of extensions services to facilitate the adoption of the new land policy. While these schemes have resulted in an increase in crop production and are well accepted by the majority of farmers, other crops such as banana, sweet potatoes and sorghum have not been promoted and have actually been reduced. In this regard, the policy should make it possible for farmers to experience how the adoption of agroforestry can generate benefits that outweigh the assignment of fields to monocropping systems. Furthermore, information related to weather forecasting and season change should be made available to farmers so that the timing of the planting season is not challenged by lack of adequate climate information.

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Chapter 4: Ecosystem services in riparian agricultural landscapes: A study of smallholder farmers' perceptions in the northern highlands of Rwanda

Abstract

Riparian zones in many rural developing regions in Africa are severely degraded at the expense of food production. Despite a recognition of the potential of agricultural landscapes to generate or maintain ecosystem services (ESs), agricultural intensification in many developing countries in Africa, including Rwanda, is being promoted as a way to support food security and economic growth at the expense of ESs on which sustainable agriculture depends. Establishing multifunctional riparian buffers within farmlands is vital for the restoration of ESs in agricultural landscapes in response to declining water quality, stream bank erosion, soil erosion, and degradation of riparian farmlands, in addition to fuel wood demands among the majority of rural smallholder farmers. Views and experiences about the importance of ESs, and strategies for restoring and maintaining those ESs were elicited from smallholder farmers in the Upper Mukungwa Watershed in northern Rwanda. This region is prone to flooding and soil erosion due to its topography and climate variability. The 430 farmers interviewed in this study recognized benefits of riparian buffers: water quality, fluvial flood mitigation, provision of fuel wood, fodder for livestock, medicinal plants, stakes to support beans, building material, soil conservation and increased farm yield. Farmers reported their willingness to adopt riparian buffers that are economically profitable and that can meet their various short-term multiple needs. However this willingness was directly related to income level. The Theory of Planned Behavior (TPB) suggests that farmers' perceptions of ESs as informed by personal experience, local sources of knowledge, and external sources of techno-scientific information, and perceived ability to restore or/and maintain ESs are essential for effective policies geared toward food

security and environmental stewardship. Smallholder farmers' perception of the importance of securing ESs through the adoption of functional riparian buffers need to be captured within a larger policy framework, the benefits of which should extend beyond short-term goals identified by farmers to a larger, multifunctional agricultural landscape that provides not only regulating but also provisioning ESs. Once we understand perspectives of farmers, we can focus on ESs as a means to promote and support sustainable agriculture.

Key words

Agroforestry, climate change, food security, soil erosion, soil fertility loss, Rwanda.

Introduction

Synergies between ecosystem services (ESs), agriculture and food security have drawn attention among many ecologists, agricultural scientists, and policy makers (Cruz-Garcia et al., 2016). ESs are benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, 2005), and could be instrumental in supporting sustainable agriculture if well managed (Cruz-Garcia et al., 2016; Reid, 2016). Ongoing discourse about the intricate synergies between agricultural landscapes and the ESs they can support suggests that rehabilitation and maintenance of functional riparian buffers, coupled with intercropping practices, including agroforestry, represent an effective strategy not only to address problems of soil loss and non-point pollution in streams due to agricultural practices (National Agroforestry Center (U.S.), 2012; Montagnini et al., 2011; Etchevers et al., 2009; Gregory et al., 2009; Sanchez, 2002; Zougmoré et al., 2000; Horwith, 1985 but also to provide additional valuable ESs including fuel wood, stakes for climbing beans, building material and medicinal plants.

Unfortunately, agricultural intensification in African countries is often being promoted as a way to support food security and economic growth (Lichtfouse, 2016; Campbell et al., 2014; Booth and Golooba-Mutebi, 2012; 2011) at the expense of ESs, including loss of organic matter, soil compaction, erosion and other impacts on soil (Lal, 2015; Cantore, 2011;Tilman et al., 2011; Wali et al., 2011; Gordon et al., 2010; Herder et al., 2010; Viala, 2008; Bossio et al., 2007; Okalebo et al., 2007; RADA, 2005; Millennium ESs, 2005; Sanchez, 2002. Understanding synergies between sustainable management of farmland that maintain ESs and improves crop yield is key to food security (Cruz-Garcia et al., 2016; Reid, 2016).

Farm management approaches, including tillage, crop diversity, crop rotation, cover cropping, agroforestry, and maintenance of riparian buffers have the potential to ensure both food security and provide ESs that support the provisioning services, including pollination, pest control, genetic diversity for future agricultural use, soil retention, regulation of soil fertility and nutrient cycling (Rasmussen et al., 2016; Schulp et al., 2014; Wunder et al., 2014; de Groot, Alkemade, Braat, Hein, & Willemen, 2010). Riparian buffers are defined as transitional semi-terrestrial/semiaquatic areas regularly influenced by fresh water, usually extending from the edges of water bodies to the edges of upland communities (Naiman, 2010). Riparian buffer contribute to provision of ESs including but not limited to intercepting and retaining nutrients and sediments, protecting banks of water bodies against erosion, improving microclimate in adjacent fields, creating more connectivity in landscapes and improving pollination (Swinton et al., 2007; Mayer et al., 2007; Mander et al., 1997). Riparian buffer trees, shrubs and grass show different relative effectiveness for providing specific benefits. For example, some tree and shrub species are very effective in stabilizing stream bank erosion while grass is very effective in filtering sediments, nutrients and pesticides. Trees are particularly also very effective in flood protection (Dosskey, 1997). The minimum acceptable riparian buffer width depends on the anticipated function of the buffer. For stream bank erosion and sediment control, a riparian buffer width might go up to 30 meters (Wenger, 1999) and soluble nutrient control requires a minimum riparian buffer width of about 100 meters (Dosskey, 1997).

Most previous studies on ESs have put more emphasis on natural habitats, such as protected natural forests for example, than human-dominated agricultural landscapes (e.g. Costanza et al., 1997; Kareiva, 2011; Sweeney et al., 2004; Cruz-Garcia et al., 2016; Schulp et al., 2014). Failure to fully incorporate the agricultural landscape in assessments of ESs such as freshwater resource quality, fuel energy, pollination and many others has potentially important consequences for management of land and resources (Rasmussen et al., 2016). In agricultural landscapes, the restoration of ESs on farmland depends for the most part on landowners goals, needs and also their knowledge or understanding (Doré et al., 2011; Bommarco et al., 2013). Therefore, it is crucial for policy makers and agricultural managers and conservation actors to understand farmers' perceptions and definition of ESs to design agricultural land management policies and tailor interventions that profitably meet farmers' goals (Greiner et al., 2009; Adger et al., 2007) while meeting national conservation and economic goals as well. However, some of the goals may be in conflict and the revision of national goals may be warranted if the other goals are to be achieved.

Studies on factors that drive farmers' adoption of particular agricultural practices have revealed a whole range of determinants which are not organized in a consolidated framework to help understand what affects farmer behaviors (e.g. (Zegeye et al., 2010; Swinton et al., 2007; Wejnert, 2002; Temesgen et al., 2009; Hassan et al., 2008; Bryan et al., 2013). The Theory of Planned Behavior (TPB), originally developped by Ajzen (1991) and supported by recent research (Kautonen et al., 2015; Case et al., 2016) presents a systematic framework for understanding the major drivers of human intentions and attitudes. TPB explains the relationship between attitudes, social norms and perceived behavioral control, also known as self-efficacy. According to TPB, the decision to perform a behavior is driven by perceptions based on past experience, perceived self-efficacy in terms of ability to perform a behavior with success, and social norms, (Ajzen, 1991; Zimmerman, 2000; Armitage & Christian, 2004; Frank et al., 2011).

TBS is useful in the context of my research because it sheds a light on factors that need to be considered or discussed for a better framing of my research and particularly with regard to drivers that could affect smallholder farmers' willingness and intention to adopt climate adaptive strategies.

According to the TPB, "human behavior is guided by three kinds of considerations: beliefs about the likely consequences or other attributes of the behavior (behavioral beliefs), beliefs about the normative expectations of other people (normative beliefs), and beliefs about the presence of factors that may further or hinder performance of the behavior (control beliefs). In their respective aggregates, behavioral beliefs produce a favorable or unfavorable ***attitude toward the behavior;*** normative beliefs result in perceived social pressure or ***subjective norm;*** and control beliefs give rise to ***perceived behavioral control,*** the perceived ease or difficulty of performing the behavior. In combination, attitude toward the behavior, subjective norm, and perception of behavioral control lead to the formation of a behavioral ***intention.*** Finally, given a sufficient degree of ***actual*** control over the behavior, people are expected to carry out their intentions when the opportunity arises. Intention is thus assumed to be the immediate antecedent of behavior" (Ajzen, 2002).

While the application of TPB has been extensively explored in health, economics and social psychology fields (Godin & Kok, 1996; Kautonen et al., 2015; Ajzen, 2002), its application in the environmental field is less common (e.g.Holloway & Ilbery, 1996; Kaiser et al., 1996; Oreg & Katz-Gerro, 2006). Yet this theory can provide critical insights for addressing the tensions between agriculture and ESs. These include failure to gauge farmers' attitudes and motivation for adopting certain farming practices that can impair our understanding of farmer adaptive behavioral choices (Frank et al., 2011). For example, recent research indicates that farmers' perception of their capabilities to produce given targets termed by Bandura (1977) as "self-efficacy" is another important component that can strongly influence farmers' intentions (Frank et al., 2011; Fielding et al., 2008; Armitage & Christian, 2004). Farmers who believe in their potential to implement best agricultural practices that foster ESs will have a positive position for the adoption of those practices. Investigating farmers' perceptions of ESs as informed by their personal experience, local sources of knowledge, external sources of techno-scientific information, and their perceived ability to restore or/and maintain ESs is essential for effective policies geared toward food security and environmental stewardship.

This study examines whether or not smallholder farmer attitudes for adoption of agricultural practices that maintain ESs within riparian buffers, agroforestry in this case, are independent of their perceptions of factors they believe could hinder or promote the uptake of agroforestry practices, and of other climatic and socio-economic factors as well. This research sets out to explicitly answer the following questions:

- What is the relationship between crop choice among smallholder farmers, belief that some crops are more vulnerable to soil erosion than others, and economic profitability?
- What is the relationship between smallholder farmer income level and crop choice?
- What factors influence smallholder farmers' willingness to maintain ESs, benefits they anticipate from the ecosystem, loss of benefits they have experienced due to ecosystem degradation, or socio-economic factors such as level of income and farm size?

- What is the relationship between choice of tree species for riparian buffer zones, trends in cultivation of certain crops, agriculture policies in Rwanda, and fuel wood needs?

To address these questions, 430 farm households were surveyed in the Upper Mukungwa Watershed of northern Rwanda. This region was chosen because it is an ideal location to study these questions given that it is in a region that has, over the past few years, been inflicted with frequent floods. Crop cultivation in many places extends to the edges of the streams and steep slopes.

Methods

Study area.

The study was conducted in the Upper Mukungwa Watershed (Figure 2) in Musanze District, Northern Province, Rwanda and covered about 60% of the Musanze District land surface area located in the northern highlands of Rwanda. The region lies on volcanic soil dominated by alfisols, andosols and entisols types (Nzeyimana et al., 2016) in a moderate-temperature and humid climate zone with an annual temperature and rainfall average of 16^0 C and 1400mm respectively (Musanze District, 2014). The rainfall seasons in the region are significantly influenced by the movement of the Inter-Tropical Conversion Zone (ITCZ) which oscillates between the northern and southern tropics over the course of one year (McSweeney et al., 2010). The Rwandan climate is characterized by a bimodal rainfall pattern with the major rainy season typically between February and June with a peak in April, and a minor rain between September and December with a peak in November. The agriculture crop calendar is organized in two seasons (Table 4-1). The region is prone to soil erosion due to steep slopes and intense rainfall (Nahayo et al., 2013; Cantore, 2011; MINAGRI, 2009; RADA, 2005).

Table 4-1

Rwanda Crop Calendar for Major Crops (Source: FAO/GIEWS accessible at http://www.fao.org/giews/countrybrief/country/RWA/pdf/RWA.pdf). Black in the table indicates sowing time, lighter black is growing time, lightest black is harvest time and black lines is lean period, which is a time during which there is not enough food

Major Food crops	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Oct.	Nov.	Dec.
Beans (A season)											
Beans (B season)											
Maize and sorghum (A season)											
Maize and sorghum (B season)											
Lean Period											

The Musanze District is 76% agricultural land. Over 90% of its population relies on smallholder agriculture for its economy. The population density, at 820 pers/km^2 (Musanze District, 2014), is one of the highest in the country and in Africa. Dominant staple crops in the Musanze District include bananas, maize, sorghum, beans, potatoes, and sweet potatoes. Most families are very poor. The Musanze landscape is dominated by agriculture.

Superpixels and farmer sampling.

Sampling units consisted of seventy 170-m radius areas called superpixels (Hartter, 2009; Goldman et al., 2008) randomly distributed across the Upper Mukungwa Watershed study area (Figure 4-1) which covers about 243km^2. In total 430 adult smallholder farmers identified as heads of households or spouses to heads of households were individually interviewed (approximately six per superpixel). Smallholder farmers who have lived in the area for at least 10 years were considered for inclusion in this study because the assumption was that they would have experience with environmental changes on their farmland in the study area; these individuals were in addition assumed to be the key individuals involved in decision-making about agricultural adaptation practices. Working with field assistants who had been trained to collect data for this research, we traveled throughout the study area to meet the smallholder farmers in their households. After arriving in a given superpixel, sampling would start from the center of the superpixel outward. Households were selected based on their availability for the interview. Where the head of a household was not available, we would interview her (his) spouse if she (he) was available for the interview. Wherever possible, we would apply gender balance to select interview participants.

Before a smallholder farmer was interviewed, we would check whether the farmer has lived in the area for at least 10 years and had farming as the main livelihood activity. Once conditions met, then we would ask the participants whether or not she (he) accepted to be interviewed. People who were drunk or had obvious mental disabilities, or were not willing to participate were not considered for the interviews. In total two men did not want to be interviewed unless they were offered a beer or cash payment, and another was drunk and it would have been inappropriate to interview him.

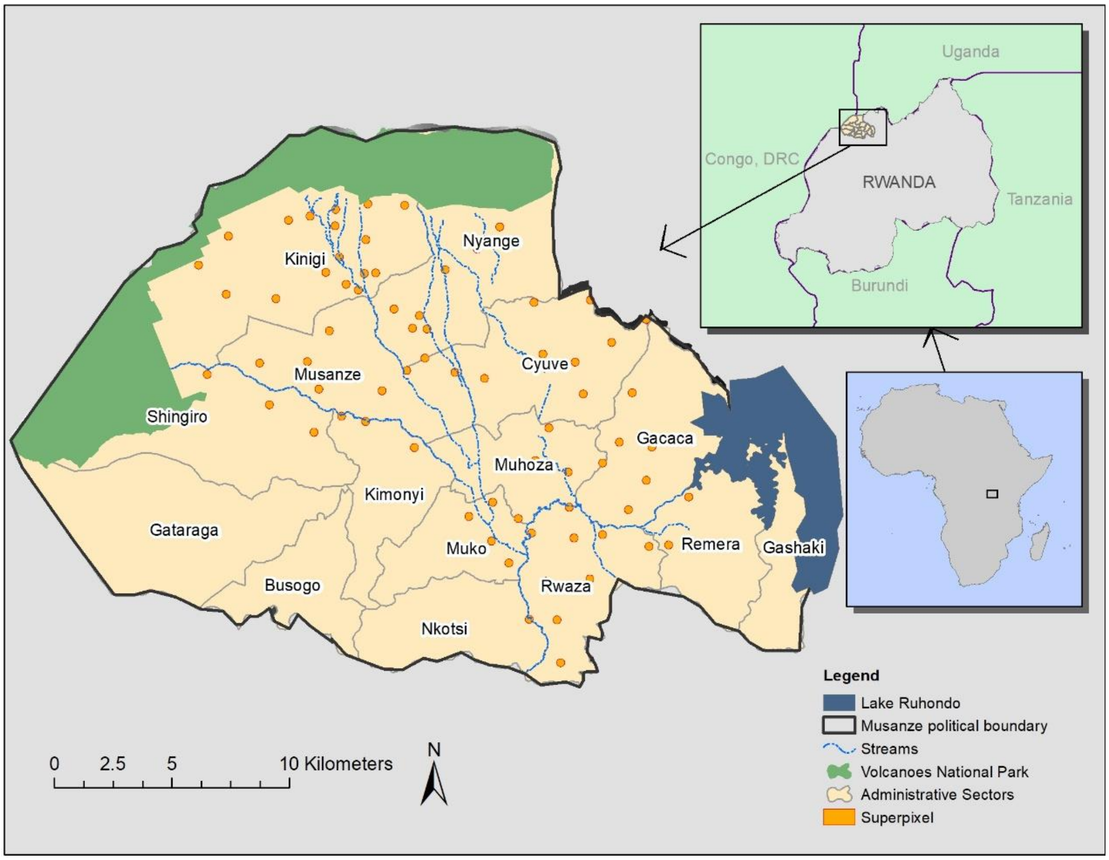

Figure 4-1. Survey superpixels (in orange circles, n=70) across the upper inhabited Mukungwa watershed study area, Rwanda

Farmer survey on perception of the importance of ESs.

<u>ESs vs. economic profitability</u>

To test the hypothesis that the maintenance of ESs is considered less important in farmers' agricultural practices than economic profitability, I explored whether criteria driving smallholder farmers' choice of plants to grow within riparian zones (dependent variables) were independent of perception of ESs farmers anticipate from functional riparian buffers, issues of concern experienced in farm plots adjacent to streams, or level of income or farm size (independent variables).

I first asked farmers: (a) their agreement on a list of criteria, including proximity to streams, slope, soil characteristics, changes of seasons, government policy, nutritional needs and economic profitability, considered to influence their decision to choose which crop to grow in any given season; (b) to what degree they believe each type of commonly grown crop is vulnerable to erosion; and (c) their agreement on whether each of the commonly cultivated crops has increased in cultivation in recent years compared to ten years ago. Possible responses were in one of three categories: 1 = strongly agree, 2 = somewhat agree, 3 = disagree. I performed a Chi-Square analysis to examine if there was an association between variable (a) and variables (b) and (c).

Perceived role of riparian buffers and maintenance of regulating ESs.

I explored whether smallholder farmers' willingness or unwillingness to establish a riparian buffer and their choices of particular plants for riparian buffers were independent of their anticipated regulatory and provisioning ESs as well as their level of income.

I used a test of independence to analyze the relationship between the perception that fluvial floods are a concern (strongly agree=1 and otherwise =0) and the perceived role of riparian buffers in abating the impact of fluvial floods (strongly agree = 1 and otherwise = 0) as well as their level of income or farm size per household. Questions I asked to the farmers in this respect included their agreement on the importance of riparian buffers in addressing the issue of floods, whether farmers were willing to adopt riparian buffers, benefits expected from riparian buffers and tree species they propose for riparian buffers.

Results

Economic profitability was ranked the highest among crop choice criteria, followed by nutritional needs and government policy. Proximity to streams, slope and soil characteristics play a relatively minor role in determining crop choice (Figure 4-2).

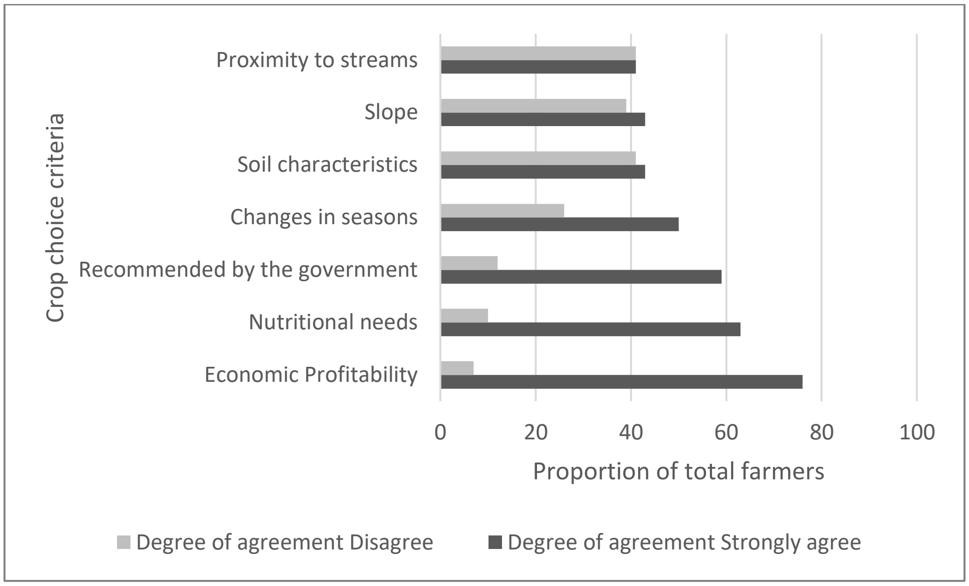

Figure 4-2. Proportion of total farmers who agree on crop choice criteria. The dark bars indicate the degree of strong agreement and the light grey bars indicate the degree of disagreement

Regarding the question about which crops are perceived to be the most vulnerable to erosion, most smallholder farmers strongly agreed that beans, corn and Irish potatoes are most susceptible to damage due to heavy rains that cause erosion (Figure 4-3).

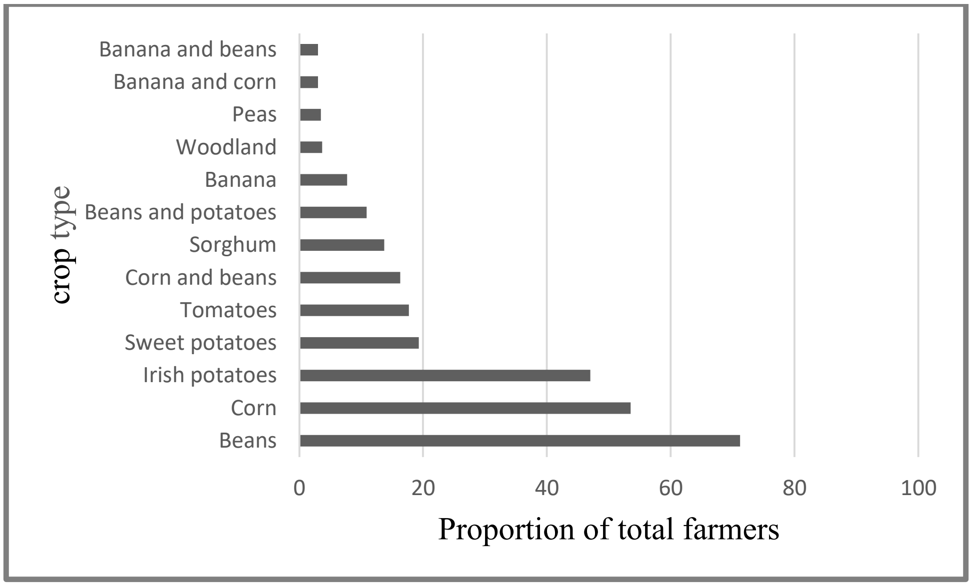

Figure 4-3. Proportion of all respondents in agreement on crop susceptibility to erosion in the Upper Mukungwa Watershed, Rwanda

Cultivation of corn, beans and potatoes, according to famers in the Upper Mukungwa Watershed, has increased more than other crops in the Upper Mukungwa Watershed in recent years compared to ten years ago (Figure 4-4).

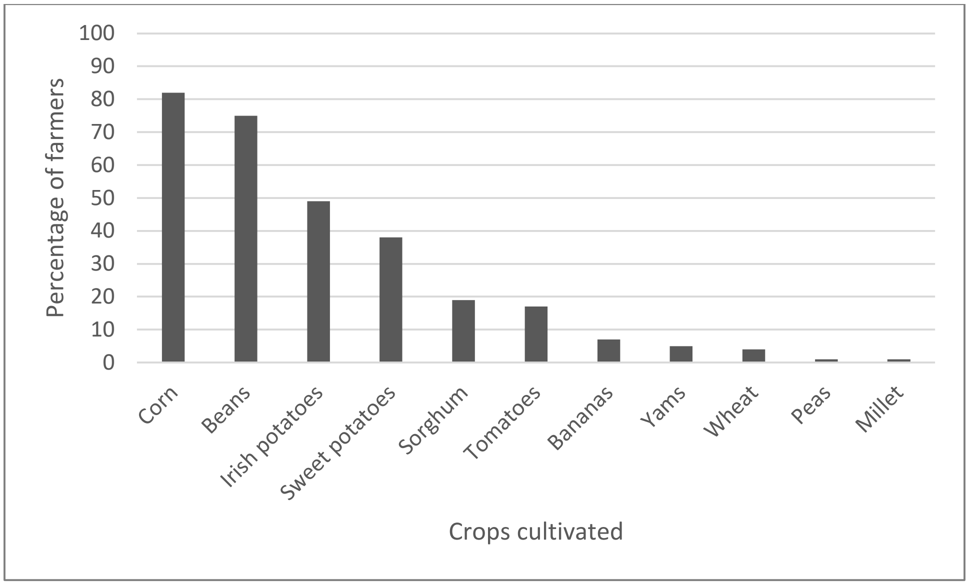

Figure 4-4. Increase in farm plots allocated to cultivation of certain crops as reported by survey participants in the Upper Mukungwa Watershed, Rwanda from 2009 – 2014. Y-axis is the percent of smallholder farmers reporting the increase of farm plots planted with specific crops

Perceived increase in the cultivation of corn, beans, and potatoes was not independent of the perception of economic profitability as criteria for crop choice ($\chi2 = 461.87$, df = 20, $p < 0.001$), beans ($\chi2 = 457.57$, df = 20, $p < 0.001$), and Irish potatoes ($\chi2 = 549.75$, df = 20, $p < 0.001$). I also found a significant association between strong agreement on economic profitability (Figure 4-2) as the predominant criteria for crop choice and strong agreement that beans ($\chi2 = 64.19$, df = 15, $p<0.001$), corn ($\chi2 = 448.28$, df = 20, $p < 0.001$) and Irish potatoes (59.05, df = 15, $p < 0.001$) are the most vulnerable to erosion compared to other crops grown in the area (Figure 4-3). Smallholder farmer perception of an increase in cultivation of beans, corn and Irish potatoes is not independent of their belief that the same crops are the most vulnerable to erosion if compared to other food crops grown in the area.

Smallholder farmers in the study plant crops right down to the streams edges. When I asked farmers which crops they would prefer to plant in riparian zones, the vast majority of smallholder farmers preferred corn and beans. Irish potatoes ranked fourth (Figure 4-5).

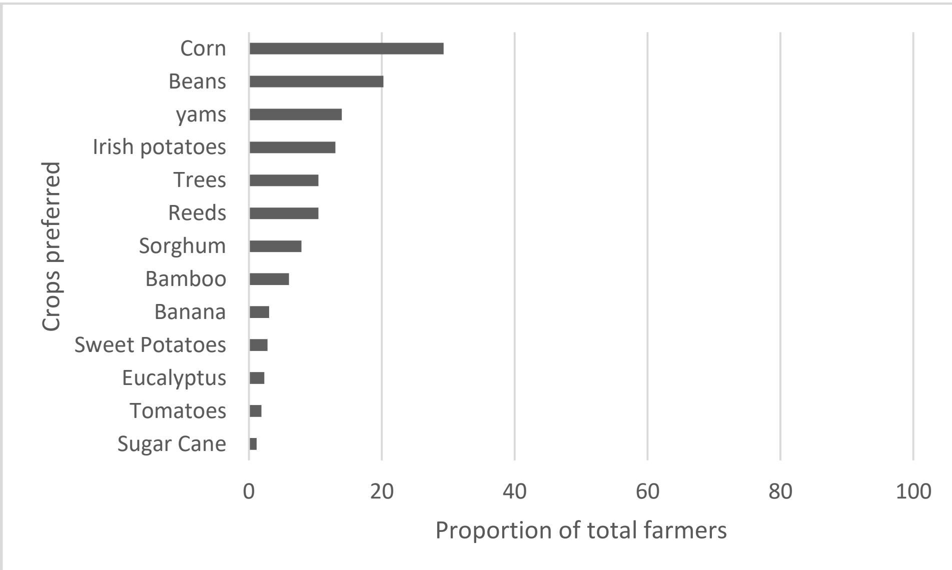

Figure 4-5. Plants preferred by smallholder farmers for riparian zones in the Upper Mukungwa Watershed, Rwanda

Perception of soil erosion, floods and riparian zones.

I analyzed the relationship between the perception that fluvial floods are a concern (strongly agree=1 and otherwise =0) and the perceived role of riparian buffers in abating the impact of fluvial floods (strongly agree = 1 and otherwise = 0) to examine if farmers in the Upper Mukungwa Watershed think that riparian buffers could be a solution to the problem of fluvial floods. There was a significant interaction between perception of fluvial floods and the role of riparian buffers ($\chi 2$ (1) = 61.47, $p < .01$). Respondents who strongly agreed that fluvial floods are a problem were also in support of riparian buffer zones as a solution to adverse impacts of fluvial floods.

There was also a significant association between the perception that farms adjacent to streams experience soil erosion and sediment and nutrient loss into adjacent streams (strongly agree = 1 and else =0) and the role of a riparian buffers in controlling sediment and nutrient loss into streams (strongly agree = 1 and else = 0) indicating these are not independent ($\chi 2$ (1) = 26.43, p < .01). Respondents who strongly agreed that soil erosion within farms proximal to streams is a serious threat were more likely to support the idea that establishing a riparian buffer would help entrap sediments and mitigate soil erosion within farmlands adjacent to streams.

Smallholder farmers' willingness to manage riparian zones and challenges.

I examined whether smallholder farmers' willingness to maintain ESs is associated with expectation of benefits from the ecosystem, with concern about the degradation of ESs they have benefited from in the past, or socio-economic factors such as level of income and farm size. I first asked participants if they were willing to adopt agricultural practices that help control soil and nutrient loss, improve water quality in streams and maintain stream bank stability (1 = Agree, 0 = Do not agree). Results show that 98% of participants reported they were willing to maintain ecosystems services on their land. A binary regression analysis shows that willingness to maintain those ESs was associated with income level (χ^2 (1) = 7.9, p = .044). The higher the level of income, the more likely the willingness to maintain ESs.

Secondly, I examined farmer level of agreement about the importance of ESs generated from best agricultural practices within riparian zones in the area, which include, among others, provision of food, fuel wood, building materials, medicinal plants, fluvial flood buffering, wood poles to support beans, and hay for livestock (1 = Strongly agree, 2 = somewhat agree, 3 =

disagree). Fuel wood, stakes to support pole beans, hay for livestock, and reduced use of synthetic fertilizers and maintenance of stream bank stability rated very important by the majority of respondents (more than 70% scores each). Another interesting finding is that, while stream bank stability was considered to be very important by the majority of respondents (70%), water for domestic use was rated very important by a smaller number of participants (less than 50% of scores) (Figure 4-6).

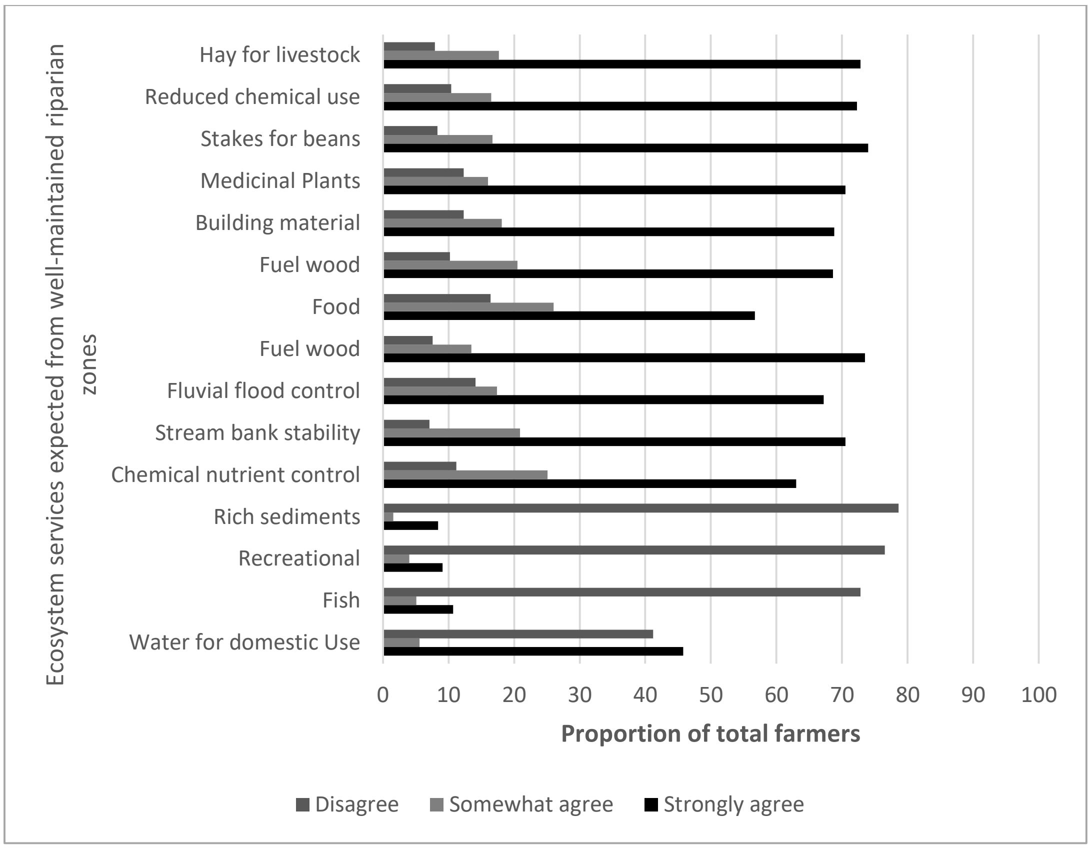

Figure 4-6. Types of ESs expected from fields adjacent to streams if well maintained riparian zones are present, according to respondents farming in the Upper Mukungwa Watershed, northern Rwanda

Lastly I asked smallholder farmers about their concerns regarding farm plots that are proximal to streams, related to erosion, water logging, and crop damage caused by fluvial floods and stream bank erosion. Results show that concern about crop damage due to erosion had the highest scores

(74%), followed by water logging (72%), fluvial floods (72%) and finally stream bank erosion (71%). A logistic regression shows a significant association between a strong agreement about the maintenance of a functional riparian buffer zone and fluvial floods experienced in fields adjacent to streams ($\chi^2(2) = 12.3$, $p = .040$). In other words, smallholder farmers who perceive that fluvial floods are of serious concern are more likely to maintain riparian buffer zones.

Plants and ESs provision: Drivers of smallholder farmer decision making.

I examined farmers' choice of plant species they consider to be important and appropriate for a riparian buffer. Smallholder farmers identified plants they consider important for the riparian buffer (Figure 4-7). Results reveal that *Eucalyptus* spp. was chosen by a majority of smallholder farmers.

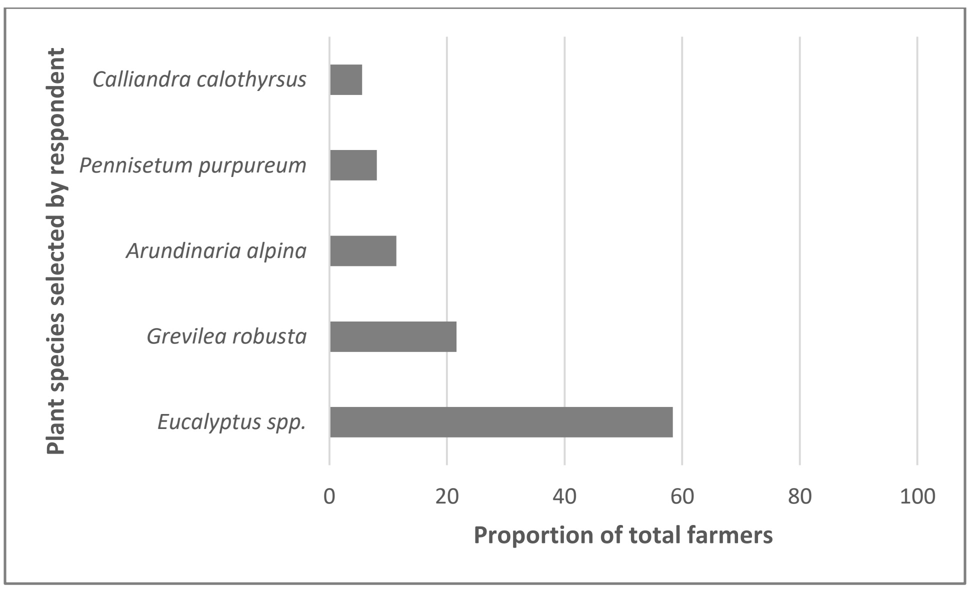

Figure 4-7. Choice of plant species for riparian buffer zones by smallholder farmers in the Upper Mukungwa Watershed, Rwanda

I tested if the choice of plants was associated with perception of the importance of ESs that functional riparian zones can offer, issues of concern experienced in farm plots adjacent to streams, level of income or farm size. Results show that the choice of *Eucalyptus* spp. was significantly associated with respondents' strong agreement that riparian buffers offer food, fuelwood, building material, medicinal plants, poles to support beans, hay for livestock and income (Table 4-2). Some smallholder farmers conceded that they prefer *Eucalyptus* spp. because "it grows fast,,….its branches offer strong and durable sticks to support beans…., and it burns well when cooking food, ….provides medicine for a cold, ….and good quality timber". Besides *Eucalyptus* spp., *Grevillea robusta* was associated with respondents' awareness of the importance of functional riparian zones to provide hay for livestock. The choice of *Arundinaria alpina* (bamboo), was on the other hand associated with respondents' awareness of the role of functional riparian zones in buffering floods, providing poles to support beans and protecting stream water. *Pennisetum purpureum* was associated with awareness about the potential of riparian buffers to provide fuelwood.

The choice of plant species types was not associated with household income level or farm size except for *Eucalyptus* spp. which was associated with income level. While *Eucalyptus* was mostly associated with provisional services (fluel wood and building material), *Arundinaria alpina* was more associated with perceived environmental regulation (flood control and retainment of sediments for water quality control).

Table 4-2

Chi-square Test Results Showing Relationship between Farmers' Choice of Plant Species for the Riparian Buffer and Benefits Farmers Expected from a Functional Riparian Buffer (The grey cells in the table show where plant choice is not statistically independent of expected ESs from riparian buffers)

	Eucalyptus spp			*Grevilia robusta*			*Arundinaria alpine*			*Pennisetum purpureum*			*Calliandra calothyrus*		
	χ2	*df*	*p-*	χ2	*df*	*p-*	χ2	*df*	*p-*	χ2	*df*	*p-*	χ2	*df*	*p-*
Food	11.525	1	0.001	.036	1	.850	2.262	1	.133	.180	1	.672	.921	1	.337
Fuel wood	19.147	1	<0.001	.563	1	.453	1.107	1	.293	6.618	1	.010	.128	1	.721
Building material	8.086	1	0.004	.259	1	.611	2.585	1	.108	.013	1	.908	.223	1	.637
Medicinal plants	8.325	1	0.004	1.713	1	.191	.566	1	.452	1.165	1	.280	.368	1	.544
Flood buffering	1.478	1	.224	2.734	1	.098	4.351	1	.037	.086	1	.770	.494	1	.482
Poles to support beans	12.738	1	<0.001	.559	1	.455	5.180	1	.023	2.730	1	.098	.566	1	.452
Less fertilizer use	.064	1	0.800	.614	1	.433	2.941	1	.086	.030	1	.863	.455	1	.500
Hay for livestock	10.429	1	0.001	5.620	1	.018	.184	1	.668	2.876	1	.090	.168	1	.683
Crops washed away	4.631	1	0.031	2.120	1	.145	.624	1	.430	1.288	1	.256	.005	1	.945
Water for domestic use	1.389	1	0.239	.041	1	.840	3.897	1	.048	1.276	1	.168	3.268	1	.071
Farm size	5.783	1	0.16	.117	1	.733	2,074	1	150	.000*	1	.983	2.858	1	.091
Income level	34.270	1	<0.001	.052	1	.819	2.035	1	.154	.033	1	.856	2.292	1	.130

Challenges to the maintenance of ESs.

Smallholder farmers reported a number of challenges that affect the adoption of activities that support ESs maintenance. Among these, the vast majority of smallholder farmers indicated the following: lack of financial assistance, lack of equipment, lack of information about needed or useful technologies, and insufficient arable land. A vast majority of smallholder farmers (73%)

reported that they get information about best agricultural practices primarily from extension services. Farmer-to-farmer extension was mentioned by about 12% of respondents, while farmers' own experimentation as source of information was mentioned by 11%.

Discussion

Preferred ESs

Farmers in the Upper Mukungwa watershed understand the importance of ESs but their understanding is virtually restricted to provisional ESs that include the provision of food primarily, then fuel wood, building material, hay/fodder for livestock, sticks to support climbing beans, and medicinal plants. This study suggests that smallholder farmers in the study area prefer to grow food crops within riparian buffer zones if they were not required by the government to plant trees and shrubs instead and they also report that the same food crops are among the most vulnerable to erosion. It seems that establishing riparian buffers that provide some regulating ESs is not one of their primary goals despite the fact that smallholder farmers in this upland region are in a region prone to heavy rains and flood events, a fact that is also recognized by smallholder farmers' reported vulnerability of the most commonly grown crops, beans and corn, to the effects of climate change. Previous studies conducted in Rwanda have also found that farmers value food over other ESs (Nabahungu & Visser, 2013b).

The Government of Rwanda's new agricultural policy involving mono-cropping systems coupled with intensive use of synthetic fertilizers and pesticides seems to align with farmers' indication that food and money from selling those food crops are most important to them; however these approaches are likely to compromise the fertility of the soil, pollination services and water quality (Isaacs et al., 2016). Agricultural ecosystems are managed by people chiefly to meet food, fiber and fuel needs especially in places where those needs are most pressing, the case in many rural regions of Sub-Saharan Africa (Garrity et al., 2010; Leach & Mearns, 2013), including Rwanda (Clay et al., 1995; Branca et al., 2011). However, agricultural ecosystems rely on a suite of supporting ESs to provide food, fiber and fuel (Swinton et al., 2007a).

The awareness and support for these services that support agricultural activities has been called "Ecological intensification" which entails the environmentally friendly replacement of anthropogenic inputs and/or enhancement of crop yield, by including regulating and supporting ESs management in agricultural practices (Bommarco et al., 2013; Tittonell, 2014). Put in the context of the present study, farmers' understanding of ESs through the lens of food production and other functions that support food production such as the provision of fuel wood for cooking, fodder for animals and sticks for climbing beans, is an indication that meeting household nutritional needs by selling the crops they grow are of primary priority. However, concerns about issues related to soil fertility restoration and water quality, which require a long-term perspective, do not seem to be part of the farmers' vision. Nevertheless, there is an opportunity for agricultural policy to bridge farmer's goals with long-term regulatory ES restoration and maintenance by providing incentives. Growing riparian trees to the maturity stage might take about ten years, a period corresponding to about 20 crop seasons. During the tree growing period, the yield of crops farmers normally grow in those riparian zones will certainly decline, thus cutting their net yearly income from the riparian farm plots. To compensate for this deficit, the government could provide incentives to offset the gap until trees have grown to a stage in which farmers experience their benefits and may not need any more incentives.

Several studies show that farmers prioritize food as the primary provisioning ESs and understand the interconnectedness between food provisioning and several supporting services such as soil conservation, nutrient cycling, water availability, soil erosion control and flood regulation, which can affect crop yields (e.g. Logsdon et al. , 2015; Lamarque et al., 2011; Smith & Sullivan, 2014; Vignola et al., 2010). However, farmers in the study area did not seem to fully understand this interconnectedness because, for example, they did not report, among other concerns, the impact of current agricultural practices or the establishment of riparian buffers on other landscapes downstream. However, research has shown that crops in individual fields are dependent on services provided by nearby ecosystems, whether native or managed, and nearby ecosystems are often influenced by their agricultural neighbors (Swinton et al., 2007a; Asbjornsen et al., 2014; Sepp, 2012). Neighboring ecosystems provide food, refugia, and reproductive habitat for pollinators and biocontrol agents; they provide wildlife habitat, and they help to attenuate some of the unwelcome effects of agricultural production, including the escape of nitrogen, phosphorus, and pesticides into non-agricultural ecosystems where they may produce undesirable impacts (Swinton et al., 2007a). Unfortunately, current agricultural systems in many parts of Africa, including Rwanda, have been, since the last century, based primarily on short-term economic rather than ecological concerns (Salam et al., 2000) often resulting in the degradation rather than maintenance of regulatory ESs (Poppy et al., 2014; Thiaw et al., 2011; Godfray et al., 2010). As a result, degradation of such regulating ESs, which include the control of erosion, floods and nutrient cycling, for example have inflicted a decline in food crop production over the past few years (Godfray et al., 2010; Fisher et al., 2013) and this impact is exacerbated by climate change (Palmer et al., 2008; Zhao et al., 2005).

In Rwanda soil erosion causes a total soil loss of about 15 million metric tons per year (Rwandan Ministry of Agriculture and Animal Resources, 2009), equivalent to losing the capacity to feed 40,000 people annually. A high reliance on scarce farmland, as is the case for Rwanda where about 57% of farms are less than 0.5 ha (Singh, 2000) with an average farm size of 0.76 ha (Booth & Golooba-Mutebi, 2012), explains why farmers prioritize food production over other ESs that require the planting of trees for example. The majority of Rwandan farmers cannot afford to devote land to trees or pasture (Malyon, 2014).

Determinants of smallholder farmers' choice of crops: environmental concerns vs. economic profitability.

In this study, smallholder farmers of the Upper Mukungwa Watershed reported that the cultivation of corn, beans and Irish potatoes has increased significantly over the past few years, compared to other food crops. This increase may be attributed to the recent agricultural intensification policy put in place by the Rwandan Government in 2008 to meet food security objectives. Farmers however reported that beans, corn and potatoes are the most susceptible to erosion compared to other crops.

The most prominent factor that drove farmers' crop choice in this study was economic profitability, followed by "nutritional value" and "government recommendations". The reason why these crops are preferred for economic reasons despite the fact that they are vulnerable to heavy rains is answered in other studies (Jayne & Jones, 1997; Smale et al., 2013). Economic profitability has been shown to be a major driver underpinning farmers' choice of farming systems and crop choice (Chouinard et al., 2008; Musshoff & Hirschauer, 2008; Cary & Wilkinson, 1997). Economic profitability includes maximization of gross margin, and minimization of working capital, hired labor, management difficulties, and risk (Sheeder & Lynne, 2011). However, other studies of farmers' decision making processes show that the assumption of "economic profitability" is not the sole driver to adopt agricultural practices. This explanation ignores the complexity of human behavior (Karali et al., 2011). Humans do not solely aim at profit maximization (Hansen, Marx, & Weber, 2004). Instead, humans tend to follow different decision-making pathways and make sub-optimal choices based on a complex web of factors, such as economic, demographic, social, cultural, psychological, technological, biophysical and environmental issues (Karali et al., 2011; Vignola et al., 2010; Keshavarz & Karami, 2014).

The Theory of Planned Behavior (TPB) brings together the economic aspect and other socio-demographic and political aspects to explain how farmer choices are influenced by multi-layered and interconnected factors. Based on the theory, adoption of any agricultural practice hinges on past behavior, attitudes, and perceived behavioral control; these factors can be significant predictors of intentions, and intentions significantly predict self-reported behavior (Zubair & Garforth, 2006). Group norms and intergroup perceptions can also be significant predictors of intentions providing support for the inclusion of social identity concepts in the theory of planned behavior (Ellis-Iversen et al., 2010; Greiner et al., 2009). My study reveals that, besides economic profitability, policy recommendations also play a pivotal role in influencing farmer decisions, which is included as an influencing factor of behavior. A study conducted in Australia (Greiner & Gregg, 2011) where nation-wide conservation programs attracted criticism for low levels of effectiveness and efficiency because farmers' perceptions and characteristics were not considered.

Choice of multifunctional riparian buffer plants.

Smallholder farmers in this study preferred to plant *Eucalyptus* spp. within riparian zones mainly because it meets multiple needs which include the provision of medicine, building material, fuelwood, sticks to support climbing beans, and shade where grass can grow for livestock. Smallholder farmers also seem to support the role of *Eucalyptus* in protecting soil against erosion. However, my results show that the choice of this tree species is associated with relatively higher levels of income. Since *Eucalyptus* is generally planted in degraded and marginal lands in woodlots (MINAGRI, 1991), one could infer that farmers with relatively larger farm size or higher income are more likely to adopt woodlots on their farms than poor smallholder farmers (Ndayambaje et al., 2013). While the adoption of *Eucalyptus* trees for riparian zones is not a new practice, it is contingent upon access to information and financial resources to make it viable. Studies show that farmers with higher household income are more likely to prefer *Eucalyptus* for riparian restoration, given greater access to information and financial resources as is the case for the adoption of any other farming practices (Franzel, 1999; Knowler and Bradshaw, 2007; Croppenstedt et al., 2003; Nhemachena and Hassan, 2007; Gandure et al., 2013; Deressa et al., 2011) given risks and costs involved over which poor uninformed smallholder farmers have little control. In this study, farmers demonstrated willingness to establish riparian buffers within their farmland proximal to streams. The types of plants they proposed to plant in the riparian zones are those which they consider to fulfill a multiplicity of functions ranging from poles to support climbing beans, fodder for livestock, fuelwood, building material, medicinal plants and flood control. Besides *Eucalyptus* spp., farmers also prefer *Grevilea robusta*, reportedly for fodder for livestock, and *Arundinaria alpina* (bamboo), because it provides sticks to support climbing beans and also contributes to flood buffering.

Eucalyptus spp. was the most mentioned tree for riparian buffer zone planting presumably because it is the most commonly used material for supporting climbing beans given its durability, but also because it is an economically high-energy fuel wood, in addition to its use for medicinal purposes. About 83% of the Rwandan population relies on wood energy for cooking (Ndayambaje & Mohren, 2011); the demand for wood resources exceeds the supply in Rwanda and the situation will continue to deteriorate (Safari, 2010). In addition, *Eucalyptus* spp. is a fast-growing, deeply-rooted tree (Robinson et al., 2006) efficient in holding soil. However, it removes moisture from soil to depths of at least 8–10 m and reduces water recharge, which can reduce baseflow in streams (Robinson et al., 2006; Bouillet et al., 2002). While it appears that farmers have their own preferences when it comes to trees species to plant within riparian zones, the Rwandan agricultural policy could encourage the planting of multipurpose trees that meet farmers'various needs and which help protect stream banks, control riparian zone erosion and nutrient leaching into streams at the same time. Farmers' understanding of economic opportunities and consequences of supporting clearly defined ecosystems services appears to influence their willingness and decision to customize their agricultural practices, by establish functioning riparian buffers for example, in order to maintain those ESs (Bommarco et al., 2013).

Perception of ESs and experienced environmental degradation.

I found an association between farmers' perception of the importance of riparian zones and their perceived experience with environment problems in and around streams, including soil erosion and fluvial floods. Smallholder farmers reported that erosion of stream banks and farmlands adjacent to streams significantly affect their households. Consequently, farmers support the establishment of riparian buffers that include the planting of trees in combination with other shrubs and grass. A study conducted in Ethiopia on the assessment of soil erosion and farmer perception of land conservation (Zegeye et al., 2010) revealed that the major cause of soil erosion mentioned by 98% of smallholder farmers was the lack of conservation structures. A study on risk perception of climate change among farmers showed a relationship between perception of increasing degradation of farmland soil and the importance of regulation services (Vignola et al., 2010). However, as evidenced by previous studies, the awareness of the importance of restoring and maintaining ESs can be overshadowed by economic interests. For example, recent increase in the use of synthetic fertilizers within the framework of a Rwandan government-mandated crop intensification program launched in 2007 has resulted in an increase in crop production, which in turn overshadows implementation of measures to control soil fertility loss in some cases.

The Rwandan Vision 2020 was launched in 2000 with a focus on the transformation of agriculture into a productive, high value, market oriented sector (Kaberuka et al., 2000; Pritchard, 2013). Started in September 2007, the Crop Intensification Program (CIP) focuses on six priority crops, maize, wheat, rice, Irish potato, beans and cassava. As a result of this policy, crop yield has increased. The production of maize and wheat has increased by 6-fold, and that of

Irish potato and cassava has tripled. The production of rice and beans has increased by 30% in the past four years, and the land area under cultivation of those crops was projected to increase (MINAGRI, 2011). Since the implementation of CIP, the cultivation of maize, beans and Irish potatoes has increased (MINAGRI, 2011) (Figure 4-8). Areas of cultivation have extended to some wetlands which have been cultivated under the government plan with the aim of growing rice as the main crop (Nabahungu & Visser, 2013b) which, over the last few years has also added to crop net production (Figure 4-9). In the face of such short-term alluring profits, it is hard for smallholder farmers who are equipped with limited information to foresee long term impacts of the CIP on water quality and availability as well as on soil fertility, just to mention a few.

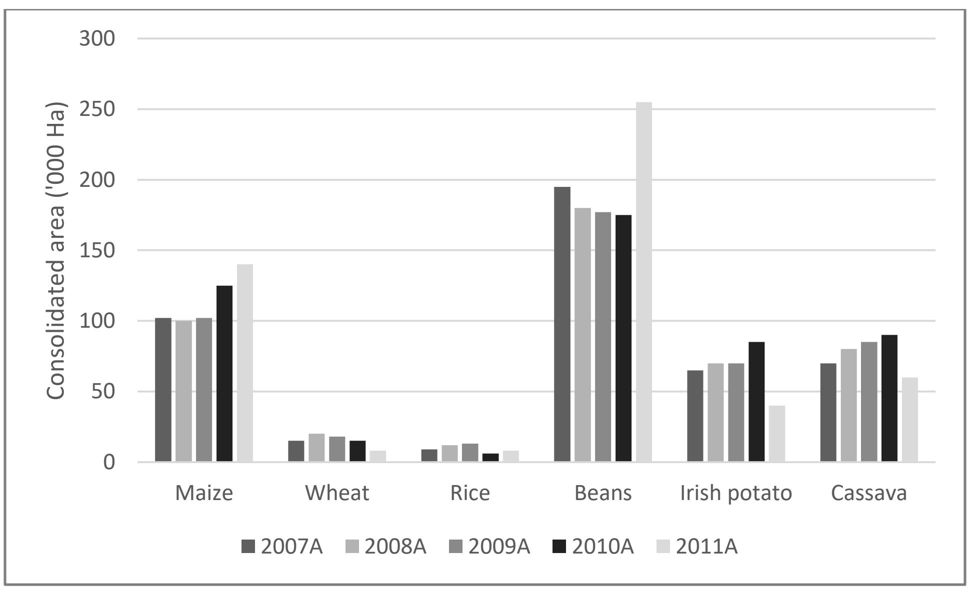

Figure 4-8. Recent trends in consolidation of land use areas under cultivation of priority crops in Season A (from September to February) in Rwanda. Source: MINAGRI (2011)

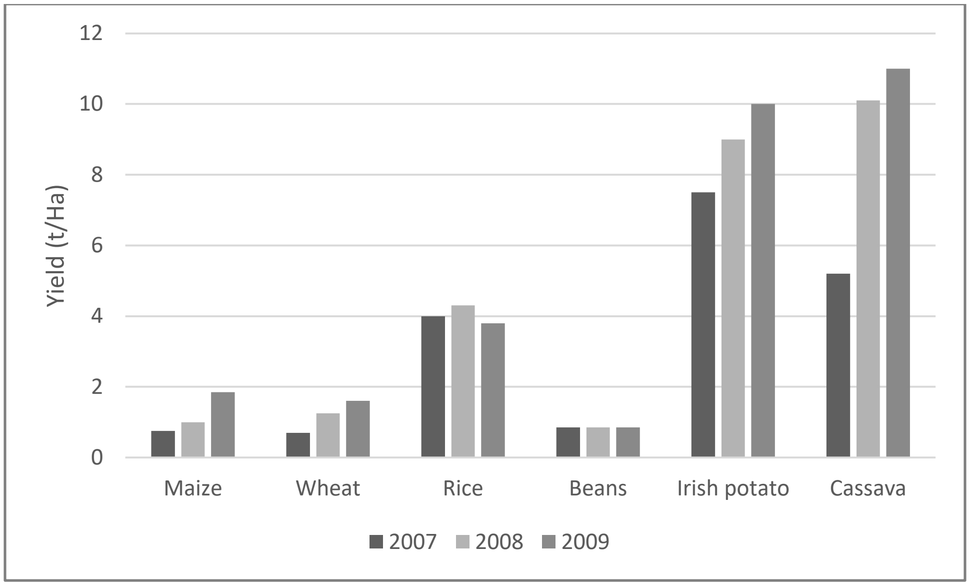

Figure 4-9. Changes in on-farm yields of major crops in response to the use of distributed inputs (improved seeds/planting materials and/or fertilizers) in Rwanda. Source: MINAGRI (2011)

In year 2016, Rwandan agricultural smallholder farmers used inorganic fertilizers mostly on Irish potatoes (73%), NPK being the most used. In the northern highlands of Rwanda, the proportion of farmers using pesticides is the highest in the country (68%), and country wide dithane was the most highly used pesticide by farmers. It is used on Irish potatoes, climbing beans and tomatoes as well as other crops (NISR, 2016). While efforts have been deployed to shift from subsistence farming to commercial farming characterized by intensive use of inorganic fertilizers and pesticides within a monocropping system, studies have shown that increased crop yields get rapidly counterbalanced by negative environmental impacts such as soil erosion, groundwater pollution, river eutrophication, excessive water use, and the development of weeds and diseases resistant to chemical control (Lichtfouse et al., 2009; Foley et al., 2011). For example, intensive agriculture in Rwanda contributes to the pollution of the Akagera River (Wali et al., 2011) and the eutrophication of Lake Victoria (Kimwaga et al., 2012).

Studies have shown that riparian buffer strips are most effective at retaining sediments and reducing the transfer of phosphorus into streams, thus reducing non-point pollution generated from intensive agriculture (Cuttle et al., 2007). However, for smallholder farmers upstream to become aware of the negative impacts of their farming practices that include increased use of synthetic fertilizers and pesticides to human populations downstream, requires the intervention of scientist working collaboratively with farmers, local NGOs involved in agriculture and policy makers. A policy change in agriculture practices to define strategies to engage scientists to work collaboratively with smallholder farmers in monitoring the impact of their agricultural practices to human populations downstream is needed to ensure sustainable management of riparian buffers upstream.

Smallholder farmers' willingness to maintain ecosystem services (ES). A vast majority of smallholder farmers interviewed within the study area reported a willingness to establish riparian buffers that restore and maintain ESs services within riparian zones as long as the practice provide profits equal or greater than those they normally get from the same plot if planted with food crops. Their willingness to maintain ESs was significantly associated with their preference for particular ES which include building material, medicinal plants, flood buffering and poles to support climbing beans. However, willingness to adopt riparian buffers was not significantly associated with level of income or farm size which might suggest that the need for ESs to be generated by riparian buffers is felt by all smallholder farmers regardless of their level of income. While some literature on riparian buffers focuses primarily on ecological benefits of functional riparian buffers for biodiversity conservation (Olson et al., 2007; Young-Mathews et al., 2010; Palmer & Bennett, 2006), water quality (Miserendino et al., 2011; Li et al., 2009; Sahu & Gu, 2009; Dosskey et al., 2010) and pollination (Cole et al., 2015; Wratten et al., 2012; Gray & Lewis, 2014; Smukler et al., 2012), other studies include the role of riparian buffers in providing supporting services such as fuel, pest control and maintenance of soil fertility (Swinton et al., 2007b; Zhang et al, , 2010). Recognition of benefits of riparian buffers to local farmers could fuel their motivation to establish those buffers in their farmland proximal to streams in order to maintain ESs they generate.

The Theory of Planned Behavior (TPB) provides a framework to understand how beliefs influence decisions about riparian zone management. Strong intentions to manage riparian zones can be associated with a favorable cost-benefit analysis that farmers are aware of, greater perceptions of normative support for the practice and perceptions of the extent to which barriers would impede management of riparian zones (Fielding et al., 2005). Perceptions of costs and benefits of riparian zone management are considered the most important factors influencing farmers' intentions to manage riparian zones (Fielding et al., 2005). Farmers with low income have a reduced capacity to grow trees on their scarce farmland; wealthier farmers tend to have more land and the financial capability to augment their energy needs by growing firewood in woodlots or purchasing firewood or charcoal (Nabanoga, 2005). The integration of riparian buffers can be acceptable to poor smallholder farmers if they are assured of realizing a timely? multiplicity of benefits (Mugonola et al., 2013; Lovell et al., 2010) that are direct and which outweigh the income they normally get from the same area if grown with food crops such as corn, beans or potatoes.

Determinants of plant choice for riparian zones.

Farmers choose plant species for riparian zone protection based on the ESs they expect from such choices. Other food crop plant species such as potatoes, beans and corn are based upon financial returns. Farmers' preference for *Eucalyptus* spp., *Grevillea robusta* and *Arundinaria alpine* are driven by the high economic value these species have and the ESs they can offer, including the provision of fuel wood, poles for climbing beans, fodder and other wood products. When farmers decide to establish or maintain a riparian buffer on their farmland, they have preferences about which plant species to use based on their goals (Lynch & Brown, 2000). Tree planting choices by farmers is believed to be determined by direct use of those tree species in their everyday life, mostly to support their farming and other household needs such as hay/fodder for livestock (Scherr, 1995; Assogbadjo et al., 2012; Roothaert & Franzel, 2001), food (Assogbadjo et al., 2012), medicines, stakes to support beans, and building material (Degrande et al., 2013). Tree planting on farmlands is also generally determined by farmers' income. Previous studies have shown that high income landowners tend to grow trees on their farmland more than smallholder farmers (Salam et al., 2000; Lovell et al., 2010; Temesgen et al., 2009). Furthermore, farmers' choice of trees could be limited by not being aware of other species they could plant. Therefore, they will tend to choose species with which they are familiar.

A vast majority of farmers in this study preferred particularly *Eucalyptus* spp. for riparian buffer planting. In Rwanda, the demand for fuel wood is high (Atangana, Khasa et al., 2014); 85% of the Rwandan population uses firewood and 0.6% use charcoal to meet their energy demands (MINITERE, 2004). Despite efforts to establish trees in agricultural fields as part of agroforestry systems, the gap between the supply and demand for fuel wood in Rwanda is increasing

(Ndayambaje & Mohren, 2011). I found a positive association between the preference for *Eucalyptus* spp. for riparian buffers and the need for fuel wood as one of the most preferred ESs from riparian buffers. *Eucalyptus* spp. is known for its fast growth, high calorific value and coppicing ability, which increases the stock density and profitability per unit area (Bagchi & Mittal, 1996; Babitha et al., 2000; Turnbull et al., 2000; Little & Gardner, 2003). Besides the provision of energy for cooking and heating, *Eucalyptus* spp. provides high-value timber for construction and making furniture and stakes for climbing beans. *Eucalyptus* spp. is the most commonly planted tree species in Rwanda (Ndayambaje et al., 2012).

Findings from this study reveal that the preference for *Eucalyptus spp*. was associated with the level of income, corroborated by a recent study by Ndayambaje et al. (2012) which found that *Eucalyptus* spp. is mostly grown by farmers with relatively higher income or larger farm size. *Grevilea robusta* was also highly ranked as a tree species of choice by farmers, and was associated with farmers' reported need for hay for livestock. In Rwanda it is a fast-growing plant with minimal competitiveness with crops (Nath et al., 2011; Bucagu et al., 2013) and with proper management, the species can be grown in plantations and on farms for firewood, poles and timber (Kalinganire, 1996; Bucagu et al., 2013). The choice of bamboo (*Arundinaria alpina*), a fast growing herbaceous species that can contribute to soil erosion control and restoration of soil fertility (Andrew & Masozera, 2010; Embaye et al., 2005) was associated with the need for poles to support climbing beans, the need to buffer the effect of fluvial floods and to improve water quality in streams by entrapping nutrients generated from agriculture. In addition, *Arundinaria alpina* does not need much management effort once it is established. It grows fast and can supplement smallholder farmers' income. However, its spikes for climbing beans are less durable than those of *Grevilea robusta* or *Eucalyptus* spp.

Theory of Planned Behavior and perception of ESs.

Failure to gauge farmers' attitudes and motivation for adopting certain farming practices can impair our understanding of adaptive behavioral choices and effective adoption of best agricultural practices (Frank et al., 2011). Recent research indicates that incorporating insights from motivation theory can enhance theorization of adaptive capacity (Frank et al., 2011). This study demonstrates that the main motivation that supports farmers' positive attitude towards the establishment of riparian zones stems both from their past experience of land loss through erosion and their need for timber and non-timber products to support food crop production and their livelihoods. The TPB has been examined with regards to the adoption of agroforestry and it has been found that socio-economic factors in association with self-efficacy, i.e. confidence in the ability to adopt agroforestry and perceived control of the adoption process, can significantly influence willingness to adopt the practice (McGinty, Swisher, & Alavalapati, 2008). Similarly, willingness to maintain ESs through the adoption of riparian buffers hinges on both farmer socio-economic status, including income, farm size, and self-perceived capacity, also termed self-efficacy, to perform tasks related to the establishment of the riparian buffer.

The benefits identified in this study were mostly provisional ESs. Less regard was given to regulating ESs such as the role of riparian buffers in entrapping nutrients from agriculture landscapes, hence contributing to water quality. While the literature supports potential water quality benefits of riparian buffer zone adoption (Swinton et al., 2007b; Zhang et al., 2010), results from this study show that farmers did not indicate any connection between current agricultural practices and quality and quantity of water in the Mukungwa river. This is an externality that the Rwandan government policy makers need to consider by using for example a payment for ecosystem services framework whereby communities downstream can contribute to the payment of best landscape management upstream. A multifunctional riparian buffer zone that meets farmers' goals and address environmental needs at the same time may therefore be an option in this landscape. The success in establishing a functional riparian buffer that contributes to improving the quality and the quantity of water in streams is contingent on addressing financial and technological challenges identified by farmers.

Any policy geared toward changing smallholder farmers' behavior in terms of agricultural practices, to be effective, needs to recognize the importance of smallholder farmers' perceived overall goals. These goals include economic profitability, satisfaction of family nutritional needs and compliance with the national agrarian policy as key drivers of behavior change for the adoption of practices that promote ESs such as the establishment and management of riparian buffers. Smallholder farmers' perceptions to support the provision of ESs through the establishment of functional riparian buffer zones could lead to positive behavioral outcomes if factors such as cost of provision, economic incentives, landowner preferences (Buckley, Hynes, & Mechan, 2012; Golkowska et al., 2016) and access to information are taken into account.

Access to information can come through extension services (Franz et al., 2010) or farmer-to-farmer extension, which, coupled with government-led extension, is considered to be effective given its contagious nature and trust among neighboring farmers (Kiptot et al., 2006; Davis et al., 2012). However, government-led extension services are limited in their reach and efficacy, and often do not reach poor, marginalized farmers including women, minorities, and people in remote areas (Davis et al., 2012; Anandajayasekeram et al., 2007). It is important to note that extension services often bring policy guidelines to farmers without discussing with them practical modalities of their implementation on the ground and without exploring realistic options (Scarborough et al., 1997; Akinnagbe et al., 2010; Deressa et al., 2011; Islam et al., 2011). This might explain why a vast majority of farmers in the Upper Mukungwa Watershed claim they get information about agricultural practices primarily from extension services, yet they also complain that they lack access to technology and technological information about establishment of economically and environmentally profitable riparian buffers. Access to credit or loans is limited among smallholder farmers in sub-Saharan Africa. Micro-credits schemes in Rwanda, for example, are widespread and are believed to contribute to the efficiency of agricultural production.

Provision of ESs within agricultural landscapes is dependent on farmers' goals, choices and awareness of environmental issues related to fields adjacent to streams, and is closely linked to experienced damage inflicted on food production by flood events. Farmers in the Upper Mukungwa Watershed of the Musanze District favor ESs that support food production or help meet priority domestic needs such as the provision of fuel wood or building material. In the face of scarce land resources, farmers appear to expect the most of trees planted on a small portion of their farmland devoted to a riparian buffer to meet their various timber and non-timber related needs. Agricultural policy should consider a farmer-centered maximization of riparian buffer performance that accommodates both farmers' goals in planting trees while helping increase soil stability and fertility. This strategy could, if well managed, also indirectly benefit other regulatory ESs such as soil nutrients, soil conservation and stream bank stability. To achieve this however, technological information about how to establish riparian buffer zones in a more economically profitable and less agro-ecologically risky way needs to be infused into farmers' practices through a more efficient, farmer-centered, collaborative approach to extension services. Agrarian policy-making should consider engaging farmers in the riparian buffer planning process for effective adoption of jointly agreed upon plans to meet provision and regulatory requirements sustainably. Given evidence from farmers' perceptions about their strong inclination for provisional ESs, educational efforts should be deployed among farmers to promote synergies between their agricultural practices within riparian zones and regulating ESs maintenance. Further research to quantify and value regulating ESs provided by functional riparian buffer zones should be encouraged and smallholder farmers should be kept informed about outcomes through extension services.

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Chapter 5: General Conclusion

Average farm size for a vast majority of households in the northern highlands of Rwanda is less than 0.75 hectare. Research on farmers' perceptions of climate change and adaptation in Africa has mainly focused on dry regions and adaptation has focused on farmers' adaptation practices, with less attention to their perceptions. This study focused on smallholder farmers in a humid region where flood hazards, soil fertility loss due to erosion are of concern and crop intensification practices meet.

My findings indicate that smallholder farmers in the Upper Mukungwa Watershed in the Musanze District believe there has been shifts in seasonal onset of rains in recent years and they reported they and they also plant their crops at variable dates; most of the farmers planting earlier in the season. Findings also reveal that smallholder farmers in the area seen an increase in areal cultivation of corn, beans and Irish potatoes, following a Rwandan government-mandated crop intensification program that started in 2007. However, those crops are reported by farmers to be the most vulnerable to climate change risks in comparison with other crops grown in the area. To sustain food crop yield within the crop intensification program setting and in the face of climate change risks, this study shows that farmers recognize the role of agroforestry in providing ecosystem services that support their food production. However, their understanding of the role of agroforestry in supporting other regulating ecosystem services such as water quality control, pollination and conservation of biodiversity is lacking, probably because smallholder farmers do not see a direct linkage of those ecosystem services and their food crop production. Nevertheless, smallholder farmers expressed their willingness to adopt agroforestry as well as to establish riparian buffers.

The study also shows that smallholder farmers who strongly agreed that soil erosion within farms proximal to streams is a serious threat were more likely to support the idea that establishing a riparian buffer would help entrap sediments and mitigate soil erosion within farmlands adjacent to streams. In the face of land scarcity, smallholder farmers support a multifunctional riparian buffer zone that meets their goals by providing fodder for their livestock, building material, poles to support climbing beans and erosion control.

Policy

The Government of Rwanda's new agricultural policy involving mono-cropping systems coupled with intensive use of synthetic fertilizers and pesticides seems to align with farmers' indication that food and money from selling those food crops are most important to them; however these approaches are likely to compromise the fertility of the soil, pollination services and water quality. This study reveals that, among other challenges, farmers lack sufficient technological capacity to implement techniques to maintain ESs, such as agroforestry, while they reported at the same time that they rely mostly on agricultural extension services for agricultural information and technology. This highlights a need for policy development to make a clear provision for effective engagement of extension services agents with smallholder farmers with regard to the uptake of agroforestry practices that contribute to food security and environmental integrity.

Finally, the chapter also reports smallholder farmers' need for financial support. Trees take up to ten years to grow to maturity and farmers need to harvest crops each agricultural season. During the tree growing period, the yield of crops farmers normally grow in those riparian zones will certainly decline, thus cutting their net yearly income from the riparian farm plots. To balance farmers' short term benefits of crop cultivation and long-term benefits of agroforestry implementation, the agrarian policy should make provision for incentives provision to poor farmers, particularly those who own farm plots proximal to water bodies and are willing to establish riparian buffers, to offset the gap until trees have grown to a stage in which farmers experience their benefits and may not need any more incentives.

Practice

Implications of famers' perceptions of environmental change and adaptation for practice are discussed in Chapter 2, 3 and 4, including recommendations to engage smallholder farmers' into the land management reform process. The Second Economic Development and Poverty Reduction Strategy (EDPRS II) for 2013-2018 recognizes environment and climate change issues to be of worthy of attention. The strategy promotes (i) mainstreaming environmental sustainability into productive and social sectors; (ii) reducing vulnerability to climate change and (iii) preventing and controlling pollution. Understanding farmers' perceptions will facilitate the adoption of strategies geared toward environmental change vulnerability reduction through the recovery and maintenance of ecosystem services. While recommendations pertain to the context of the northern highlands of Rwanda, they could be transferred to other regions in Rwanda where smallholder farmers are facing similar environmental challenges.

Suggestions for Future Research

This dissertation represents a contribution to understanding smallholder farmers' perceptions of environmental change and adaptation and sets a stage for future research. First there is a need to gauge farmers' perceptions of environmental change across all agro-ecological zones in Rwanda to assess the variability of perceptions in the face of varying socio-economic and geophysical contexts. To date, information about farmers' preference for particular tree species for riparian buffers and agroforestry under various socio-economic and geographic context, for example, is lacking. A comparative study on farmers' perceptions of environmental change and adoption across the country will help agrarian policy makers design a policy that reflects farmers' goals and interests.

Secondly, results from this study suggest that research on agroforestry move from research stations that are inaccessible to smallholder farmers to farmers' own field plots. This should deviate from benefiting merely government institutions to the ownership of the research from research stations by farmers themselves. Such a strategy could provide an opportunity for smallholder farmers to learn the agroforestry technology and to participate in a cost/benefit analysis of the adoption of agroforestry and to engage actively in the establishment of riparian buffer zones. Once the technology is adopted by smallholder farmers participating in the study, the technology uptake among neighboring farmers could be effective.

Thirdly, research is needed that looks at various agroforestry practices to assess their economic and environmental contribution to environmental change adaptation. A few studies have examined agroforestry in Rwanda and have documented the practice in various parts of the country but there is minimal quantitative documentation of economic and environmental value of various agroforestry systems in Rwanda and how agroforestry could be reconfigured to fulfil those functions.

As the Rwandan agrarian policy strongly promotes crop intensification programs, there is the possibility to reconcile monocroppping systems associated with the program and agroforestry. Therefore, research is needed to examine a feasibility analysis pertaining to the sustainable, environmentally and economically profitable integration of agroforestry with crop intensification. Such research could contribute to the national goal of moving away from subsistence towards market-oriented agriculture and also contribute to meeting smallholder farmer need for fuel, stakes for climbing beans, building material, fodder for animals, while also contributing to soil conservation.

Lastly, for riparian buffers to be effective, a study is needed to look at the effectiveness of various riparian buffer configurations in meeting smallholder farmers' goals while providing environmental benefits at the same time. In a bigger picture, it would be valuable to conduct a study on how agroforestry practices and maintenance of functional riparian buffers upstream can contribute to water quality downstream and how the reduction of the cost of water treatment downstream can contribute to providing incentives for best agricultural practices upstream.