Deforestation and forest degradation in southern Burkina Faso: Understanding the drivers of change and options for revegetation

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Academic dissertation
for the Dr. Sc. (Agric.&For.) Degree

To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public discussion in Auditorium XII at the University of Helsinki Main Building, Unioninkatu 34, on Friday 13 May 2016, at 12 o'clock noon.

Helsinki 2016

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ISBN 978-951-51-2075-5 (paperback)
ISBN 978-951-51-2076-2 (PDF)
ISSN 0786-8170

Unigrafia Oy

Helsinki 2016

ABSTRACT

Tropical deforestation and forest degradation (DD) contribute approximately 15% of the annual global anthropogenic greenhouse gas (GHG) emissions. However, they are considered the main emissions sources in most developing countries. Despite the potentials of forest and tree plantations to mitigate the effects of climate change through carbon sequestration, DD still remains a challenge in Africa. Globally, the forests of Africa are the most depleted of all tropical regions, with only 30% of historical forest area still remaining. In addition, Africa's complexity in terms of its geography, politics, socioculture, economy, institutions etc. is an indication of why Africa has defied all simple solutions in addressing DD: a phenomenon considered location- and situation-specific.

The biophysical setting of Burkina Faso exposes the central and northern region to drought and desertification. Such conditions have caused human migration to the southwestern regions, which offer better opportunities for rain-fed agriculture, but also experiences the highest rates of deforestation. On the other hand, the ongoing regreening process in the Sahel through tree planting and assisted natural regeneration of indigenous tree species is a signal for regrowth and revegetation. This study contributes to understanding the drivers of DD in four adjacent village communities in the Ziro province, southern Burkina Faso in the light of the forest transition theory. Specifically, this study assesses the drivers of DD at the farm/forest level and also identifies options for regrowth/revegetation. This dissertation consists of four articles (studies I, II, III, and IV). Studies I and II refer to stage two of the forest transition curve (forest frontier) while studies III and IV refer to stage four of the curve (forest/plantations/agricultural mosaics).

Various methods were used during data collection, including interviews with key informants, focus group discussions (FGDs), two hundred household interviews (studies I, II, and III), gathering a list of local botanical knowledge from 48 participants (study IV), and a field survey. Qualitative and quantitative methods were used in analyzing the data.

Low agricultural production expressed in the sizes (areas) and ages of farms together with land tenure insecurity were found to lead to increased deforestation. Results suggested that a 10% increase in farm size would result in a 4% increase in annual deforestation (study I). Furthermore, results in study II indicated that non-poor and fairly poor farmers contributed more towards activities considered environmentally degrading, such as deforestation, overgrazing etc., than the poorest farmers. On the other hand, the adoption of sustainable land management practices was relatively low among the poorest farmers.

Tree planters were mainly farmers who held large and old farm areas, were literate and relatively wealthy, held favorable attitudes towards tree planting, and had participated in a farmers' group for several years (study III). Local knowledge of tree species was found to be unevenly distributed in relation to gender, age, ethnic group, and location. Plant species assigned relatively high use-values for livelihood include *Adansonia digitata*, *Parkia biglobosa*, *Vitellaria paradoxa*, and *Balanites aegyptiaca*. On the other hand, *Adansonia digitata*, *Tamarindus indica*, and *Ficus thonningii* were considered more important for environmental protection (study IV).

The dissertation concludes that tenure insecurity and low agricultural production contribute to DD at the farm/forest level on the one hand while tree plantations, land management practices, such as fallow, zai pits (a traditional soil and water conservation technique), and assisted natural regeneration of indigenous tree species are important activities promoting regrowth/revegetation.

Key words: Tenure insecurity, land management, smallholder farmers, field expansion, poverty, Burkina Faso

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PREFACE

The image of my community twenty-five years ago still remains fresh in my mind. With my own eyes I witnessed the conversion of forest into oil palm plantations and other non-forest land uses. The eastern part of my community was named 'jungle bay' because it used to be a home for diverse forms of plant and animal species and a catchment area for many streams. Deforestation affected the catchment area and streams began to dwindle while some disappeared. Just like other people, I saw a problem emerging and wished to be part of the solution. This opportunity to conduct research in the West African Sahel of Burkina Faso as part of the BIODEV project created a chance for me to investigate the drivers of land-use change and options for mitigating its effect.

My doctoral studies would not have been possible without the involvement of others at different stages of the process. I wish to thank Prof. Emeritus Olavi Luukkanen who gave me the opportunity to join VITRI for my doctoral studies. I am indebted to my PhD supervisor Prof. Markku Kanninen, who has supported me throughout my career and guided me from the beginning to the end of my dissertation. Thanks for the useful and constructive comments you made in my papers and thesis summary. In addition, I wish to thank my supervisor for the full financial support he made available for my studies since 2013 through Work Package 3 (WP3: National Policies and Capacity Strengthening) of the Building Biocarbon and Rural Development in West Africa Project (BIODEV). Without support from the BIODEV Project, my dreams would have remained a dream. I wish to acknowledge the International Tropical Timber Organization (ITTO) and the Mikko Kaloinen Foundation for their financial support.

Many thanks to the Center for International Forestry Research – West African Regional Office (CIFOR-WARO) for the logistic support and co-authorship. In this regard, I wish to thank Dr Zida Mathurin, Mr. Michael Balinga, Dr Dayamba Djibril, Dr Issa Ouedraogo, Dr Augustin Kabore, Mr Herman Kambire, Ms. Mawa Karambiri, Mr. Koffi Kouame Christophe, Mr. David Denis, and Mr. Rabdo Abdoulaye. To my field assistant Mr. Oumarou Bognini, I say thank you for your assistance during data collection. My appreciation also goes to the community members of Cassou, Vrassan, Kou, and Dao villages, who took the time to provide answers to my questionnaires. In addition, I am sincerely indebted to all my co-authors: Dr Fobissie Kalame, Mrs. Nadia Djenontin, Dr Kaisa Korhonen-Kurki, Dr Houria Djoudi, and Dr Edinam Glover. Once again, thank you Dr Fobissie Kalame for you encouragement and advice during my studies. Furthermore, I extend my heartfelt gratitude to Prof. John Sumelius and Dr Irmeli Mustalahti for acting as pre-examiners for my dissertation. Thank you for your valuable comments that have improved my dissertation.

In VITRI many thanks go to Dr Eshetu Yirdaw, Dr Markku Larjavaara, Dr. Kurt Walter, Dr. Mohamed Elfadl, Dr Maarit Kallio, Dr. Jörn Laxén, Michael Marboah, Biar Deng, Adrian Monge, Mustafa Fahmi, Wafa Abakar, Dipjoy Chakma, Edmund Asare, and Tabi Ferdinand for their moral support. I particularly wish to thank Dr Maarit Kallio for the useful comments she made on my third paper.

Finally I wish to give a big thank you to the Etongo's and Esoh Itoh's families and my fellow brethren in the household of faith for their moral support and prayers. Last but not least, very special thanks are due to my dearest wife, Ayuk Etongo for her support, patience, and understanding throughout my studies. To God Almighty be all the glory.

Helsinki, January 2016
Daniel Etongo

LIST OF ORIGINAL PAPERS

This thesis is based on the following original articles:

I. Etongo, D., Djenontin, I.N.S., Kanninen, M., Fobissie, K., Korhonen-Kurki, K., Djoudi, H. 2015. Land tenure, asset heterogeneity and deforestation in Southern Burkina Faso. Forest Policy and Economics 61: 51-58.

II. Etongo, D., Djenontin, I.N.S., Kanninen, M. Poverty and environmental degradation in southern Burkina Faso: An assessment based on participatory methods. Land (Submitted).

III. Etongo, D., Djenontin, I.N.S., Kanninen, M., Fobissie, K. 2015. Smallholders' Tree Planting Activity in the Ziro Province, southern Burkina Faso: Impacts on Livelihood and Policy Implications. Forests 6, 2655-2677; doi: 10.3390/f6082655

IV. Etongo, D., Djenontin, I.N.S., Kanninen, M., Glover, E.K. Assessing use-values and relative importance of trees for livelihood values and their potentials for environmental protection in southern Burkina Faso. Environment, Development and Sustainability (Accepted).

Daniel Etongo introduced the research idea, organized the field activities, and collected all the data in each of the studies (I–IV). In study I, Daniel Etongo analyzed the data together with Nadia Djenontin while Daniel Etongo prepared the manuscript, which was later revised by Markku Kanninen, Kaisa Korhonen-Kurki, Fobissie Kalame, Nadia Djenontin, and Houria Djoudi. For study II, Daniel Etongo analyzed the data which was later commented on by Nadia Djenontin. Daniel Etongo prepared the manuscript while Markku Kanninen and Nadia Djenontin revised it. Daniel Etongo analyzed the data and prepared the manuscripts of studies III and IV, while Markku Kanninen, Fobissie Kalame, and Nadia Djenontin (study III), and Markku Kanninen, Nadia Djenontin, and Edinam Glover (study IV) revised the manuscripts.

LIST OF MAIN ACRONYMS AND ABBREVIATIONS

ACI	African Cashew Initiative
ANR	Assisted Natural Regeneration
CDM	Clean Development Mechanism
CNFS	Centre National de Semences Forestieres
DD	Deforestation and Forest Degradation
DFID	Department for International Development
EKC	Environmental Kuznets Curve
FAO	Food and Agricultural Organization of the United Nations
FGDs	Focus Group Discussions
FMGs	Forest Management Groups
FMNR	Farmer-Managed Natural Regeneration
FRA	Forest Resource Assessment
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LULUCF	Land Use, Land-Use Change and Forestry
MAD	Mean Annual Deforestation
MLE	Maximum Likelihood Estimator
NGOs	Non-governmental Organizations
OLS	Ordinary Least Squares
PPA	Participatory Poverty Assessment
REDD	Reducing Emissions from Deforestation and Forest Degradation
SLM	Sustainable Land Management
SSA	Sub-Saharan Africa
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
WCED	World Commission on Environment and Development

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1. Introduction

1.1. Land use, land-use change and forestry (LULUCF)

Within the context of climate change policy, emissions, and removals of greenhouse gases from direct human-induced impacts on the land are accounted within the sector known as land use, land-use change, and forestry (LULUCF). Land use and land-use change are driven by sociocultural, economic, institutional, political, and environmental factors. With the recognition of the sustainable development concept, environmental and sustainability concerns have begun influencing land-use policy (Lambin et al. 2001, Foley et al. 2005). The report by the World Commission on Environment and Development (WCED), also known as the 'Brundtland Commission Report' promoted sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). Do changes in land uses and resource management strategies in sub-Saharan Africa and the Sahel take into account environmental and sustainability concerns? In practice, natural resource management in such a complex environment does not often result in a win-win situation of environmental improvement (Leach et al. 1999). As such, LULUCF activities can either improve or degrade the environment (Cowie et al. 2007).

Human activity inevitably impacts the land and in combination with other factors may yield positive or negative outcomes (García-Oliva and Masera 2004). As expressed in the Stockholm Declaration (United Nations Conference on the Human Environment, 1972): "Man is both a creature and moulder of his environment".

Such a statement implies man is an agent of change with his needs placing a demand on the environmental systems. The first major human-induced land-use changes are associated with the burning practices of indigenous peoples, for example in Australia (Yibarbuk et al. 2001) beginning in the late Pleistocene and North America in the early Holocene (MacCleery 1999). These practices altered fire regimes, during which aboriginal mosaic-burning replaced infrequent intense lightning-induced fires. The resultant effect was the displacement of forests by woodlands and grasslands, which depleted forest resources. In this study, forest is land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent while woodlands is land not defined as "forest" but spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of 5–10 percent. In both cases, land that is predominantly under agropastoral systems is not included (FAO 2015).

Despite such an early utilization trend in Australia, African forests are currently the most depleted of all tropical ecosystems with only 30% of the historical forest areas still remaining (Chidumayo and Gumbo 2010). Land degradation is additionally estimated to affect 10–20% of the world's drylands (Millennium Ecosystem Assessment 2005). Natural resource degradation has resulted from both natural factors and anthropogenic modifications of the landscape. The upshots of these modifications are microclimatic variability, rising commodities and land prices, deforestation, loss of biodiversity (Luck 2007), and loss of traditional livelihoods practiced by indigenous people (Alston et al. 2000).

The drivers of land-use change are multifaceted and cannot be reduced to a few variables; rather they operate at different levels and scales in the human-environment linkage (Lambin et al. 2003). These drivers are divided into two broad categories: proximate and underlying causes. Proximate causes are typically human activities operating at the local level. These activities affect land use and impact forest cover. They include shifting cultivation and cattle ranching, wood extraction through logging or charcoal production, and infrastructural development such as transportation, markets and settlements. On the other hand, underlying causes do not directly cause deforestation but influence the proximate causes. This category includes a complexity of economic issues, policies and institutions, technological factors, sociocultural, and demographic factors (Geist and Lambin 2002, Lambin et al. 2003). The main drivers of change in the Sahel include e.g. population growth, high dependence on wood energy, rising demand for agricultural products, government incentives on cotton cultivation, and field expansion into forest areas (Ouedraogo et al. 2015).

Apart from activities considered to drive DD, some activities influence the revegetation/regrowth of forests. Activities such as enrichment planting in forest management, cropland management, grazing land management, and assisted natural regeneration of trees have the potential to increase forest cover. Practices enhancing forest growth maximize carbon sequestration in forest biomass: matching species to sites, good site preparation, managing weed competition, and applying fertilizers to correct nutrient deficiencies and maintain fertility. Practices enhancing forest growth will also build soil carbon stocks through increased organic matter addition (Höhne et al. 2007).

Furthermore, an increase in the use of trees in agricultural landscapes through agroforestry systems has a large potential to sequester carbon, both in woody biomass and soil (Vagen et al. 2005), due to the vast land areas used for agricultural purposes (Montagnini and Nair 2004). Integration of a tree component will improve both the resilience of the farming system and enhance carbon sequestration. Trees on farm known as parklands dominate the Sahel and this system has thrived for centuries. The indigenous tree species in the Sahel regenerate through assisted natural regeneration, with a potential for regrowth/revegetation (Acharya 2006). Tree-based interventions are therefore invaluable in combating desertification, particularly through the reduction in soil erosion (Garrity and Stapleton 2011). Furthermore, agroforestry programs are major components of the national and regional action programmes in the Sahel under the United Nations Convention to Combat Desertification (UNCCD).

Tree belts may lower the water table locally, permitting cropping on sites that have become unproductive due to shallow saline groundwater (Robinson et al. 2006). Interventions through afforestation and reforestation programs have been implemented and are ongoing in the Sahel and Burkina Faso. The ongoing regreening of the Sahel could not have been possible without human intervention. In the Maradi and Zinder regions of Niger, over 200 million trees have regreened an area of approximately 5 million hectares (Sendzimir et al. 2011). Such figures are an indication of land-use dynamics resulting from various interventions improving the regrowth and revegetation of such a fragile ecosystem.

1.2. Tropical deforestation

Deforestation and forest degradation (DD) in the tropics is globally acknowledged due to its important role in global warming (Kanninen et al. 2007, Douglas and Simula 2010). Considered a priority in Agenda 21 of the United Nations Conference on Environment and Development (UNCED) in 1992, DD has dominated international forest policy efforts during the last four decades (Humphrey 2006, Saastamoinen 2009). The focus has been increasingly directed towards local, national, and regional adaptation and mitigation approaches, and interventions or mainstreaming approaches. An estimated 80% of the carbon emitted into the atmosphere between 1850–2000 originated from the conversion of forests to non-forest land uses (Houghton 2006). Reducing deforestation rates is considered a relatively low-cost and effective option for climate change mitigation when compared to proposed clean development mechanism (CDM) interventions (DeFries et al. 2010).

Understanding the drivers of DD is believed to be fundamental for developing policies and measures that can alter current trends of forest loss and degradation (Rudel et al. 2009). Despite this window of opportunity, demographic, economic and social changes in the tropics continue to exert considerable pressure on forests (Mayaux et al. 2005, Perz et al. 2005). Tropical forests, just like other forest types suffer from land-use change, which is considered a major driver of forest loss (Achard et al. 2002, Gbetnkom 2005). These changes occur through activities such as agricultural expansion, commercial logging, fuelwood demand, and infrastructural development etc. (Geist and Lambin 2002). DD affects ecosystem goods and services that are vital for livelihood and environmental protection. A study suggested that land-use changes are likely to have a greater impact on biodiversity loss than climate change, nitrogen deposition, biotic exchange, or increased carbon dioxide concentrations (Sala et al. 2000).

A recent study found that 30% of the global land area has been degraded since the 1980s while land improvement has concurrently occurred on approximately 3% of the global land area until 2013 (Le et al. 2014). What then drives forest and land degradation in the tropics? These drivers are numerous and location-specific in nature, with the same factor likely having contradicting effects on land degradation (Nkonya et al. 2013). For example, poverty can contribute to DD in some contexts while encouraging revegetation in others. Irrespective of the existing land degradation contexts, such as deforestation, this process is driven by proximate and underlying causes. The proximate causes of land degradation are direct causes consisting of biophysical factors and unsustainable land management practices. On the other hand, the underlying causes are more complex, cutting across institutional, socioeconomic, and policy factors such as population density, poverty, land tenure security and property rights, access to markets, agricultural subsidies, and taxes etc. (Nkonya et al. 2013, Mirzabaev et al. 2015). The policy environment and prevailing local conditions are important factors in understanding the drivers of land degradation. DD are thus complementary because deforestation has also been found to lead to degradation and vice versa (Kanninen et al. 2007).

According to Hosonamu et al. (2012), more than 60% of tropical DD occurs outside forest concession areas. Agricultural intensification is considered an option to reduce field expansion, but agricultural intensification in Burkina Faso and other sub-Saharan African countries has unfortunately been an uneven process that has incurred social costs and disparate environmental trade-offs (Gray 2005). Furthermore, DFID (2004) corroborate the view that an increase in cultivated areas by farmers remains the best possible option to augment low farm production in African agriculture, which is considered to be extremely low. Approximately 80% of the growth in African agriculture is estimated to originate from the expansion of cultivated areas (Kates et al. 1993). When faced with an increased demand for agricultural production e.g. through population growth, or low production due to low inputs, farmers' reactions may not be to invest in new technology, soil fertility improvements, or shift to other crops. Rather, they will probably begin by gradually expanding their cultivation onto unused land (Reenberg et al. 2003, Chomitz, 2007).

However, agricultural expansion is a common process displaying characteristics reasonably different from intensification (Oksen 2000). The expansion of cultivated areas has profound effects on the natural environment as anthropogenic activities convert forests to crop and rangelands (Achard et al. 2002). Anthropogenic modification affects the provision of ecosystem goods and services, which now places more demand on natural resources resulting in forest and soil degradation, and the loss of biodiversity and emissions due to land-use change (Sala et al. 2000, Lambin et al. 2003). Tropical deforestation and degradation contribute approximately 20–25% of the annual GHG emissions (Greig-Gran 2006, 2008), with recent estimates of 15% (Harris et al. 2012) and are considered the main sources of emissions in most developing countries (Karousaki 2006, Hosonuma et al. 2012).

The rate of tropical DD has increased (Engel and Palmer 2008) by an average rate of 13 million hectares per year between 1990 and 2000 (FAO 2006, 2010). The drivers of DD are many and varied, cutting across policy and institutions to sociocultural and economic factors (Kaimowitz and Angelsen 1998, Pearce 2001, Geist and Lambin 2002, Kim 2010, Boucher et al. 2011, Hosonuma et al. 2012). These drivers have been grouped into two categories: the proximate/direct and the underlying/indirect drivers of deforestation (Geist and Lambin 2002). Understanding how to mitigate the effects of the underlying drivers of deforestation still remains a major challenge in most developing countries. These challenges are reflected in the inadequacy and failure of policy interventions and activities to address resource management strategies that are considered environmentally degrading (DeFries et al. 2010).

1.3. Deforestation and forest degradation in sub-Saharan Africa and the Sahel

Land cover is constantly changing with different patterns and magnitudes in sub-Saharan Africa and the Sahel in particular. The conversion of grasslands, woodlands, and forests into croplands and pastures has risen dramatically during the last two decades. For example, disturbances in tropical dry forests have resulted in the fragmentation, degradation, and in some cases disappearance of these forests (Mayaux et al. 2005, Hartter et al. 2008, Mbow et al. 2013). The main drivers behind these changes are a combination of population growth (Stéphenne and Lambin 2004), rising demand for agricultural products, dietary changes, agricultural trade and adjustment, dependence on wood energy, and recurrent bush fires etc. (Angonese and Grau 2014, Ouedraogo et al. 2015). Dealing with the drivers of land cover dynamics remains a challenge because of their complexities and in some cases their interrelatedness. However, a study suggested that 'forest transitions' are invaluable in understanding land-cover change (Rudel et al. 2005). The term 'forest transitions' was coined by Mather (1992) to explain changes that occur in forested land as societies undergo industrialization and urbanization.

Two sequences of events have been use to explain forest transition: 'the great transformation' (Mather 1992) also referred to as the 'economic development path', and the 'forest scarcity path' (Rudel et al. 2005). In the 'economic development path' forest transitions begin during a period of deforestation. Forests initially decline in extent as growing numbers of cultivators, with help from loggers, clear forested lands and convert them into fields to meet growing demands for food and fiber for the increasing human population residing in cities. Eventually, deforestation declines alongside agricultural expansion. Within the context of this path, arguments concerning forest recovery after agricultural expansion are likely to take two general forms. First, farmworkers leave their land for better-paid non-farm jobs. This loss of labor raises the wages of the remaining workers and renders additional agricultural enterprises unprofitable. Under such prevailing circumstances farmers abandon their more remote, less productive fields and pastures. These lands then revert to forest as urbanization and economic development causes the loss of farm labor.

Secondly, in the 'forest scarcity path', the loss of forests during the agricultural expansion creates a countervailing tendency. Increasing demand of forest products from a growing population with little opportunities to import forest products will act as an incentive for landowners to plant trees instead of crops (Rudel et al. 2005). Such a situation makes tree planting an increasingly attractive activity due to the high prices available for tree resources. Higher deforestation rates in developing countries have led to forest loss. These losses are expected to create a situation of forest scarcity that will in turn provoke reforestation and afforestation interventions. Forest transition in China is associated with the 'forest scarcity path' (Foster and Rosenzweig 2003).

The rate of forest cover loss in Africa is alarming: 5.3. million ha of forest were lost annually between 1990–2000, corresponding to an annual rate of 0.8% (FAO 2001), while from 2000–2010, an estimated 3.4 million ha were lost annually, equivalent to an annual rate of 0.5% (FAO 2010). However, the annual rate of forest loss varies from country to country. The highest rates occurred in Nigeria and Tanzania during 2000–2010, with an annual loss of 0.410 and 0.403 million ha respectively (FAO 2010). Furthermore, an estimated 10–20% of the world's drylands are degraded (Safriel et al. 2005). In the drylands of Africa, annual net changes in tree cover and other wooded land have been estimated at -0.91 Mha (0.34% annual rate of loss) and -0.89 Mha (0.20%), respectively, between 1990 and 2000, while the annual net change from dense to open tree cover was -0.39 Mha (Bodart et al. 2013).

While the burning of oil and gas contribute to global warming in developed countries (Kim 2010), DD causes GHG emissions in developing countries (Hosonuma et al. 2012).

Deforestation annually causes the release of 1.6 billion tons of GHG into the atmosphere (Baumert et al. 2005, FAO 2006). With such a trend, Africa is likely to become warmer, and this warming is likely to be higher than the global annual mean throughout the continent, with more impact on drier areas rather than the humid tropics (Pouliot et al. 2012). The annual mean temperature in the West African Sahel is projected to increase by approximately 2.0 to 6.0˚C from the present level (IPCC 2007), while the mean annual precipitation is expected to increase by 6–20% by 2025.

1.4. Deforestation and forest degradation in Burkina Faso

According to the FAO Global Forest Resource Assessment (FRA) based on land classification, the loss of forest areas in Burkina Faso is estimated at 56 490 km², representing 21% of the national territory (FAO 2009). Though high quality empirical national-level data on deforestation in Burkina Faso are not available (Westholm and Kokko 2011), annual estimates fall between 0.91% and 1.03% (FAO 2010, Fischer et al. 2011). The biophysical setting of the country exposes the central and north region to drought and desertification (Fontes and Guinko 1995) and over 80% of the country's forests (inclusive of community-managed forests) are found in the southwestern and eastern region (FIP 2012). A study in southern Burkina Faso found a drastic reduction of dense forestland from 69.7% in 1986 to 31.4% in 2002 and 40.6% in 2006 (Ouedraogo et al. 2010). The decrease during 1986–2002 was estimated at 1.45% per annum, representing the highest rate of deforestation within the country.

Compared to other regions of the country, southern Burkina Faso offers better opportunities for rain-fed agriculture, fuelwood supply, year-round fodder supply, and forest products (FIP 2012). An estimated 70% of the country's population is rural and depends on agriculture and livestock for their livelihoods (Paré et al. 2010). In addition, the highest amount of rainfall occurs in the south Sudanian eco-region. The difficult conditions for agrosilvopastoral activities in the central and northern region have led to human migration to the southern region in increasing numbers in the last 30 years (Ouedraogo et al. 2009). Population growth through natural increase and human migration with more contribution from the latter have increased pressure on natural resources. The demand on croplands has increased, thereby reducing the possibilities of retaining fallows while bringing new areas into cultivation (Gray 1999, 2005). The expansion of farmlands into forests has been identified as a major driver of DD in the country (Reenberg et al. 2003). However, field expansion is driven by other factors apart from land scarcity. For example, the productivity of African agriculture is extremely low and has not improved in decades (DFID 2004). Thus, in the absence of sustainable land management practices and fallow, farmers are likely to expand their fields into forest areas, especially if no strict control is implemented.

A study in southern Burkina Faso revealed that 50% of the community-managed forests in the Sissili province were converted to open woodland during 1986–2006, with an average increase of 0.46% per annum (Ouedraogo et al. 2010). The area covered by croplands increased from 7.5% in 1986 to 26.6% in 2006. Ouedraogo et al. (2009) document a very strong correlation between human migration and forest degradation/deforestation/agricultural expansion in southern Burkina Faso. Interestingly, the migration pattern in Burkina Faso is rural-rural migration because the majority of the population is rural and dependent on farming and livestock (Henry et al. 2004a). This movement involves the Fulani and Mossi ethnic groups from the north and central regions to the southwestern region of the country (Sawadogo 2006). Increasing aridity in the north and central regions appears to be a strong determinant, increasing the likelihood of long-term migration (Henry et al. 2004b). For the period 1962–2006, Idinoba et al. (2010) documented an increase in the mean annual temperature of 1.5˚C and a 20-mm rainfall decrease in Burkina Faso.

1.5. Activities and factors influencing revegetation/regrowth in Burkina Faso

Is forest transition expected to occur in such a region as the Sahel despite its problems of drought, desertification, DD, and the complexities governing access and control of natural resources that affect sustainable land management practices? A study in the Sahel found that a transition to intensified land use initially caused a loss of woodlands but later resulted in the planting and protection of useful trees on farm (Mortimore and Turner 2005). In addition, two studies in the drylands of Africa have documented some success stories leading towards the more sustainable and productive management of natural resources by smallholder farmers (Mazzucato and Niemeijer 2000, Reij and Steeds 2003). The regreening process in the Sahel is one such success story (Olsson et al. 2005). For example, the Maradi and Zinder Regions of Niger experienced a dramatic regrowth/revegetation of more than 5 million hectares of land (Sendzimir et al. 2011).

Though increasing rainfall over the last few years is certainly one reason, regrowth/revegetation in the Sahel cannot be attributed to any single actor, policy, or practice. Rather, this dramatic regreening process is the outcome of multiple actors, institutions, and processes operating at various levels, times, and scales (Sendzimir et al. 2011). Farmer-managed natural regeneration (FMNR), a set of practices farmers use to foster the regrowth of indigenous trees on agricultural land, has drawn substantial attention to influencing regrowth through assisting natural regeneration (Haglund et al. 2011). Furthermore, water harvesting techniques have also been found to accelerate the rehabilitation of plant diversity (Larwanou and Saadou 2011) and reduce the loss of soils (Sidibé 2005) in the parklands of Burkina Faso.

In the parkland system indigenous trees are deliberately selected and maintained when converting natural woodland to farmland, a practice that has existed for centuries in the Sahel (Gijsbers et al. 1994, Teklehaimanot 2004, Bayala et al. 2014). These indigenous trees regenerate naturally and are preserved on the farm because they provide various products to farmers such as income, food, wood, medicine, fodder, construction materials, boundary markers, and ecological functions e.g. carbon sequestration and soil fertility enhancement (Bayala et al. 2011, Faye et al. 2010). Although parklands are dominated by a few tree species, they also contain a wide range of other species depending on the original vegetation, the level of vegetation degradation, the needs of farmers, and local knowledge concerning the species' uses (Boffa 1995, Bayala et al. 2006, Bayala et al. 2011). Thus, in addition to assisting the natural regeneration of indigenous tree species, tree planting activities by smallholder farmers have been invaluable for improving tree cover in the landscapes of southern Burkina Faso (Etongo et al. 2015).

1.6. Study aims and objectives

The overall aim of the study was to understand the drivers of DD in southern Burkina Faso and options for regrowth/revegetation. The purpose was also to assess the underlying drivers of deforestation in southern Burkina Faso and to offer suggestions for livelihood improvement and environmental protection.

The specific objectives of this study were to:

(i) Analyze the role of land tenure and asset heterogeneity in relation to deforestation in southern Burkina Faso (Study I).
(ii) Investigate the connections between poverty and environmental degradation based on participatory poverty assessment (PPA) methods in southern Burkina Faso (Study II).
(iii) Examine the socioeconomic and perceptional characteristics of tree planters and non-tree planters, their reasons for planting trees, and willingness to continue this activity under current tenure arrangements (study III).
(iv) Assess use-values and the relative importance of trees for livelihood and environmental protection in southern Burkina Faso (study IV).

This study consists of six chapters. Chapter 2 presents a general overview and the related literature concerning DD and regrowth/revegetation, finally narrowing down to the forest transition theory. The general overview section in chapter 2 reviews the drivers of DD and revegetation in relation to drivers operating at the local, regional, national, and international levels. The reviewed literature was used to explain the forest transition theory and where each study in question refers to on the forest transition curve. Chapter 3 describes the study area and methods applied in the individual studies. For more detail on the methods, see the individual studies located at the end of this dissertation. Chapter 4 summarizes the results of studies I–IV while chapter 5 discusses the implications of our findings in relation to deforestation and forest degradation, and potential options for a transition to occur. Chapter 5 discusses studies I and II in relation to stage II of the forest transition curve while studies II and IV are examined in relation to stage IV of the forest transition curve. Chapter 6 summarizes the key findings of this study and also provides some recommendations for tackling these problems.

The hypotheses addressing each of the specific objectives are:

(i) Land tenure status and available household resources influences deforestation (study I).

(ii) Rural poverty leads to household engagement in activities considered environmentally degrading (study II).

(iii) Farmers' tree planting activities are motivated by household socioeconomic and farm characteristics; incentives received; financial benefits from tree-based resources; access to markets; and farmers' participation in forest management/farmers' group (study III).

(iv) Ethnobotanical knowledge for livelihood values and environmental protection is influenced by age, gender, activity, and location (study IV).

2. Theoretical framework

2.1. General

The dynamics of tropical deforestation in sub-Saharan Africa (SSA) over the decades have defied any easy explanation (Rudel 2013). This is because land-use decision-making between forest- and non-forest land uses is marred with complexities in governance and institutions in relation to land access (Geist and Lambin 2001). As such, the theoretical framework of the present study will be linked to the forest transition theory (Mather 1992) because it provides a logical reasoning for understanding forest-cover changes. This will require drawing on two conceptual areas in the literature concerning land-cover dynamics; (i) mechanisms and drivers of DD and land degradation, (ii) regrowth/revegetation and afforestation activities. Household behavior on land-use decision-making and the role of macroeconomic policies are important in understanding the drivers of land-use change. As indicated in the general framework of LULUCF (Fig. 1), the causes of tropical deforestation are considered as underlying, proximate, or direct and agents (Kaimowitz and Angelsen 1998, Geist and Lambin 2002). Despite some disagreement between the direct causes and agents regarding the final causers of DD, this study will consider the agents as causers of DD. Angelsen and Kaimowitz (1999) additionally justified that agents are the final causers of DD in their study.

However, our study focuses on the issues within the box (see Fig. 1) that do not operate independently but are influenced by the underlying factors outside the box. These factors, be they inside or outside the box, are interrelated and depending on the location or prevailing conditions interact to cause DD that might vary in extent and magnitude. For example, though a household socioeconomic situation conditions the direction of deforestation, the magnitude of the changes that occur on non-forest land uses are influenced by policies and market conditions (Brondizio et al. 2002). This suggests that understanding specific policies and markets shaping various development agendas remains a powerful instrument for understanding environment-society interactions for specific places over time (Klepeis and Turner 2001). It should be noted that policies and markets can act as incentives or disincentives for forest transition as follows: (i) by prompting forest clearing for other land uses i.e. DD, or (ii) by promoting regrowth/revegetation and afforestation (Brown and Pearce 1994, Kaimowitz and Angelsen 1998, Contreras 1999).

It is thus imperative to determine the outcomes that are likely to occur based on specific policies and market situations. For example inflation is related to policies that promote deforestation as an underlying driver through land speculation. Such policies increase public spending and money supply, which promote economic growth by stimulating demand for agricultural products, thereby accelerating deforestation (Pacheco 2006). On the other hand, a deflationary policy reduces public spending and money supply, and its effect on forests can be ambiguous (Kaimowitz and Angelsen 1998). These forces are called the underlying drivers of DD and include macro-economic policies and markets operating at the national and international levels, which interact among themselves to generate sources of government inefficiency (see Fig. 1). Policies at these levels may affect prices for agricultural products in the global market place, thereby playing a decisive role in driving forest clearing by introducing changes in interest and exchange rates that in turn influence decisions on private investment. Kaimowitz and Angelsen (1998) suggested that policies such as real-exchange rate depreciation, along with reducing tariffs and trade restrictions and lowering export taxes for agricultural products will in turn improve the relative prices of these products, thereby prompting deforestation.

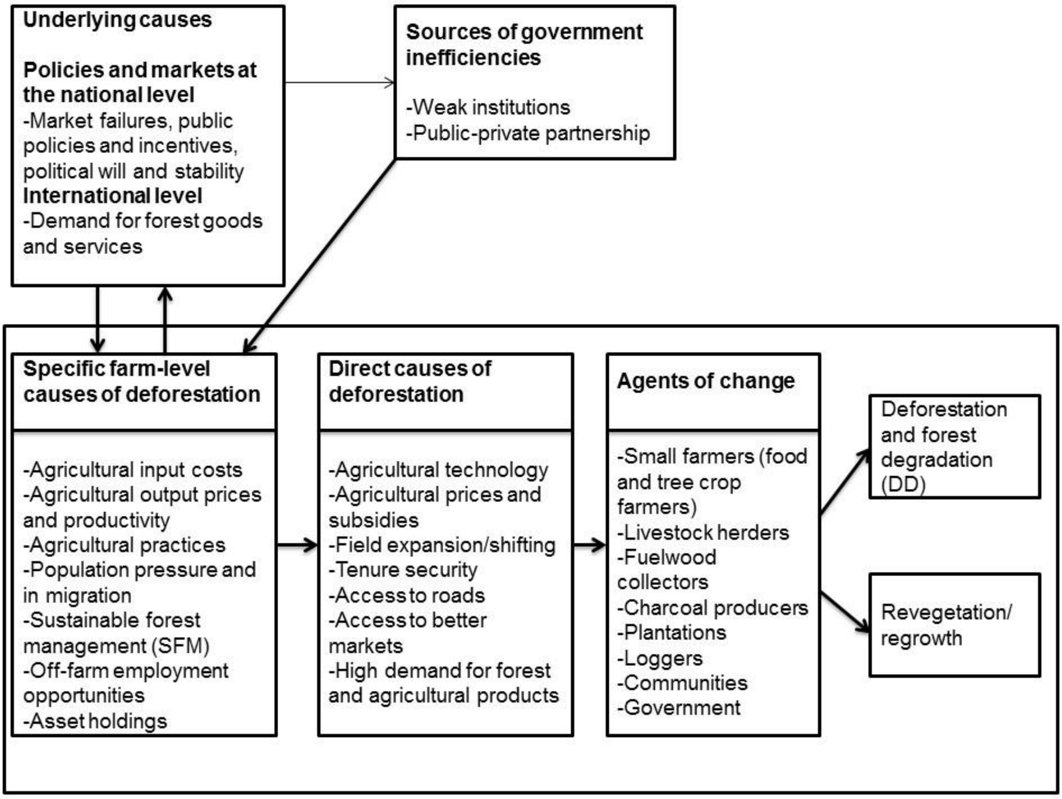

Figure 1: General framework of LULUCF. Modified from Geist and Lambin 2002.

Unlike macro-economic policies that are likely to be ambiguous, sectorial policies are less so and have more direct effect on the land-use decision-making of landholders. For example, providing subsidies for agricultural inputs, or lower interest rates on financial resources allocated to farmers is likely to keep prices for agricultural products artificially high. This will improve the competitiveness of agricultural production, which may directly impact forest clearing (Brown and Pearce 1994, Contreras 1999). An increase in deforestation may additionally result from promoting agricultural technologies that are capital-intensive and oriented towards export products (Angelsen et al. 2001). For example, cotton is the main export crop in Burkina Faso and its cultivation requires animal traction, making it a capital-intensive venture that only the relatively wealthy farmers can effectively participate in (see study II). Aside from being capital-intensive, cotton cultivation has been identified by some studies as a major driver of deforestation in Burkina Faso (Bonnassieux 2002, Sawadogo 2006, Kaminski et al. 2011, Kambire et al. 2015), thereby corroborating the above view.

Lack of adequate public policies and in some cases lack of enforcement have succeeded in reinforcing the underlying drivers of DD (Palo 2000). The relationship between a country and its position and role in the global economy (i.e. dependency theory) can therefore easily promote DD or revegetation (Ehrhardt-Martinez 1998). As such, deforestation is likely to result from three types of dependency: export/trade dependency, debt dependency, and an influx of foreign capital. Market expansion and liberalization, and agricultural intensification (Diouf and Lambin 2001) are considered processes of land-use change that are linked to globalization. Despite efforts from international environmental agencies advocating for institutional reforms (Glicken 2000, Benjaminsen 2001, Pearce et al. 2003), commercial and subsistence rights to forests between the government and local population are still persistent in some Francophone West African countries (Ribot 2001).

Furthermore, conventional wisdom suggests that unclear tenure will promote forest clearing (Southgate et al. 1991, Reid et al. 2000) while tenure security increases forest area (Alston et al. 2000, Brasselle et al. 2002, Mekonnen 2009, Robinson et al. 2013). Existing farming systems may introduce different types of tenure arrangements. According to Angelsen (2007), tenure security may operate along a continuum in shifting agricultural systems. In such arrangements, tenure security is likely to be weakened as fallow years become longer, leading to higher deforestation rates. Irrespective of the arrangement in place and how they affects or favors the forest composition depends on existing incentives that can promote or hinder land investment. Studies in the Sahel (Larwanou and Saadou 2011, Haglund et al. 2011) and Burkina Faso (Place and Binam 2013) have proved that investing in the assisted natural regeneration of indigenous tree species promotes regrowth/revegetation. Apart from improving tree cover, assisted natural regeneration has been found to improve tenure security in the Sahel because land improvement is considered a sense of ownership in this region (Weston et al. 2015). Policies designed to improve land tenure security may thus have an ambiguous effect on forests (Lele et al. 2000).

On the other hand, a new technology promoting more intensive agricultural practices may pull resources out of extensive agriculture at the forest frontier. In this case, deforestation rates are likely to lessen (Angelsen and Kaimowitz 2001, Angelsen 2007, Chomitz et al. 2007). The role of improved agricultural technologies in relation to deforestation is ambiguous. This ambiguity brings us to the question “can yield improvement offer a solution to both tropical forest loss and agricultural demand, or could they pose further challenges to tropical conservation?” (Carrasco et al. 2014). Dealing with complex issues, such as DD, requires caution because the relative strength of the forces in operation remains crucial in determining whether agricultural technologies can improve or induce forest loss. For example, a new technology that increases profitability will be more attractive to farmers thereby leading to forest loss. Pricing policies on agricultural products play a decisive role because lower prices may reduce the area under cultivation and vice versa. According to Angelsen and Kaimowitz (2001), agricultural technologies that are labor-intensive will concentrate more labor to smaller areas and therefore lessen deforestation.

In Figure 1, farm-specific causes can directly influence the direct causes, thereby influencing agents to engage in activities that drive DD or forest regrowth. An increase in agricultural output prices and productivity in addition to availability of off-farm employment could cause the agents to lessen deforestation (Angelsen 2007). On the other hand, population pressure on the land (e.g. natural increase and in-migration), agricultural practices, such as field expansion due to very little opportunities for intensification, and little off-farm employment will lead to higher deforestation rates. A study in Burkina Faso found that human migration is a threat to environmental sustainability (Ouedraogo et al. 2009). In addition, the productivity of African agriculture has not improved for decades due to low inputs, and therefore one possible option for farmers to increase their yields is to increase the cultivated area (DFID 2004). This finding has been supported by two studies in Burkina Faso, where agricultural intensification resulted in field expansion (Reenberg et al. 2003, Gray 2005).

According to Argrawal and Angelsen (2009), better market access will result in higher farm-gate prices of agriculture and forest products and in increased demand. Demand for these products will raise the incentives for long-term management while concurrently heightening short-term exploitation, thereby leading to deforestation. Government failure to provide tenure security to forest managers may discourage long-term management. Low prices for timber and illegal logging practices may additionally promote unsustainable forest management (Rhodes et al. 2006). Furthermore, households with more resources and unsecure tenure are not likely to invest in land, thereby causing degradation. Two studies found that the assisted natural regeneration (ANR) of indigenous trees on farmlands in the Sahel improves tenure security (Place and Binam 2013, Weston et al. 2015). Even people with secure tenure but little resources may not engage in ANR and tree planting because of the longer delay for trees to attain harvesting age. The likelihood of environmental degradation occurring in such a situation with little or no investment on the land is therefore higher.

Apart from activities causing DD, regrowth/revegetation may be the outcome in certain situations. For example, water harvesting techniques, such as Zai, have been found to improve not only soils but also the vegetation of Burkina Faso and the Sahel (Lenhardt et al. 2014). Zai is an indigenous land management practice in the Sahel, incorporating planting pits typically measuring 20–30 cm in width, 10–20 cm in depth, and 60–80 cm apart. It is an ancestral practice for regenerating degraded and crusted soils by breaking up the surface crust to improve water infiltration (Danjuma and Mohammed 2015). This technique increases both tree cover and diversity in Burkina Faso (Sawadogo et al. 2001). Thus, farmers practicing Zai will promote regrowth/revegetation compared to non-practitioners. Tree regrowth is expected to be greatly improved for farmers practicing Zai in addition to ANR and tree planting. Little opportunities for importing forest products in a situation of growing demand (population increase) may also lead to price increases due to scarcity. Land owners may plant trees instead of crops in such a situation to take advantage of favorable tree resource prices compared to crops. If such a condition prevails over time, revegetation will occur, reflecting the last stage of forest transition.

Lastly, the 'economic development path' of forest transition presents another scenario that could lead to revegetation. Within this context, the availability of better-paid off-farm employment as a result of urbanization and economic development causes the loss of farm laborers. This loss raises the wages of remaining workers thereby turning more agricultural enterprises unprofitable. Such circumstances thus cause farmers to abandon their more remote and less productive fields, which eventually return to forests (Rudel et al. 2005). Interventions from the government and non-governmental organizations (NGOs) may reduce field expansion by providing support through training and materials to farmers. To promote regrowth, government support in the form of subsidies to farmers can change the trend of field expansion associated with low agricultural inputs. Governments should make farm inputs available to farmers at low interest rates (Epule et al. 2014). African countries could adopt the Latin American model where compensation is given to farmers who decide to protect the rainforest instead of expanding farms (Tollefson 2009). Such a financial mechanism could be similar to REDD+ and may be supported through the African Development Bank.

2.2. Review of approaches repelling deforestation

Various approaches have been developed to provide explanations for the causes of deforestation. Keeping track of these numerous approaches has been challenging. Based on the chosen scale criteria, deforestation can be assessed at the farm/forest, regional, national, and even global level. The methods used are grouped into analytical, empirical, and simulation models (Kaimowitz and Angelsen 1998). Analytical models use theoretical constructions of the interrelationships between the factors involved in deforestation. Empirical models use statistical methods to deduce the theoretical relationships between these factors from a large number of data sets, whereas simulation models use observed parameter values that are substituted in a theoretical model to analyze the outcomes of different scenarios (Stéphenne and Lambin 2001, Gray 2010).

Furthermore, some approaches are temporal in nature, thereby making them more or less static while others are dynamic. This implies each approach is guided by specific assumptions. These assumptions are an indication that each approach seeks to fulfill different objectives. The issue of scale is part of the objective that each approach attempts to fulfill. Economic models have thus been designed to understand the drivers of deforestation at the macro and micro scales (Kaimowitz and Angelsen 1998). As such, the choice of approach for analyzing the causes of deforestation or for predicting their extent are location- and situation-specific (Gray 2010).

Macroeconomic models analyze aggregate data at the sub-national/regional, national, or even global level. Macroeconomic approaches have been applied in the study of deforestation in Sudano-Sahelian countries (Stéphenne and Lambin 2001), the Congo Basin (Megevand et al. 2013), Brazilian Amazon (Dale et al. 1994), Belize (Chomitz and Gray 1996), and India (Chakraborty 1994). Macroeconomic factors, such as population growth, poverty, economic growth along with foreign debt and trade liberalization, are invaluable in understanding DD. The Environmental Kuznets Curve (EKC) hypothesis is another example using aggregate data, and describes the relationship between income levels and deforestation (Kuznets 1955). This theory suggests a u-shape curve in which environmental degradation initially intensifies and later reduces as income per capita increases over time (Panayotou 1993).

The EKC hypothesis additionally appears to be more of an empirical regularity and the dynamics behind the curve have been given several explanations. As such, economic growth may increase both the demand and production of agricultural commodities, thereby increasing deforestation rates (Kanninen et al. 2007). On the other hand, agricultural intensification and the availability of off-farm employment opportunities can offset such a pattern. An increase in per capita income for reducing DD does not work in many developing countries, especially in the Sahel. Asset holding is thus more feasible in assessing wealth, especially in a country, such as Burkina Faso, where approximately 70% of the population is rural and depend on informal economy. Application of the EKC hypothesis in the rural areas of developing countries, especially in Africa, should therefore consider assets rather than income.

The land rent theory is another approach in which the location of land together with prices and input costs may affect and shape land uses differently (von Thünen 1966). Land users are expected to deforest because alternative land-use options are considered more profitable than forestland uses (i.e. they yield higher land rent). The von Thünen theory provides a better explanation for deforestation. According to this theory, land is allocated to the use with the highest land rent (surplus or profit). Factors determining the marginal net benefits between agriculture and forestry activities provide the reasons for deforestation at the farm/forest level (Angelsen 2007). Some of these factors include crop prices, input costs, available technologies, agro ecological conditions, rotation periods etc. Distance to a commercial center is considered a key aspect in this theory, which shapes land use with rent expected to decrease as the location becomes more remote. The assumption that land use yielding the highest rent is chosen is therefore likely to happen (Angelsen 2007).

The land rent or profit from agricultural activities can thus be considered a declining function of distance as follows (Angelsen 2007):

$$r(d) = py - wl - qk - c - vd, \tag{1}$$

where: agricultural production per ha (yield) of the homogenous land is given by (y), produce sold in a central market at given price (p), labor and capital required per ha (l and k), with input prices w (wage) and q (annual costs of capital). The cost of enforcing property rights is given as c, transport costs per km is denoted as v, and the distance from the center as d.

Based on the consideration of distance, it becomes imperative to consider the agricultural frontier i.e. the distance at which agricultural cultivation is no longer profitable [r (d) = 0]. To derive a simple model that yields several key insights on the immediate causes of deforestation will combine the zero rent definition of the frontier with equation (1) to give (Angelsen 2007):

$$d^{frontier} = \frac{py - wl - qk - c}{v}, \tag{2}$$

where (p) is higher output prices, (y) technologies that increase yield or reduce input costs (l, k), thereby making agricultural expansion more attractive. Lower capital costs (q) in the form of better access to credit and lower interest rate follow in the same direction. Higher wages (w), such as the costs of hiring labor or use of family labor, work in the opposite direction, as do the high costs of defending property rights (c). Reducing access costs (v) or new and better roads also provide a great stimulus for deforestation. Empirical studies in sub-Saharan Africa (DFID 2004) and Burkina Faso corroborate the view that low agricultural inputs have weakened the intensification process, resulting in field expansion as an alternative strategy to increase farm productivity (Reenberg et al. 2003, Gray 2005).

In the open economy approach, analysis is limited to comparative statics that point to the direction of effects, but not to their magnitude. In the subsistence or 'full belly' approach, the key assumption is that households only seek to meet a pre-established consumption target and once that target is met, they lose interest in working. Such an assumption seems unrealistic. Unlike analytical models, farm-level empirical and simulation models can handle relatively large numbers of independent variables. Models in this category require a lot of costly data and their conclusions only apply to the cases studied, which may or may not be representative of other areas. Furthermore, cross-sectional farmer regression models, though good for studying the relationships between farmer characteristics, access to market, and services and forest clearing, tell little about the effects of important variables such as prices, capital accumulation, and population change. Though such variables can be examined using panel data, this kind of data are only rarely available (Kaimowitz and Angelsen 1998).

As indicated in the literature, microeconomic models attempting to analyze the causes of DD should avoid generalizations, and farm/site-specific, farmer-specific, sociocultural, economic, and institutional factors (study I, II) should rather be considered (Angelsen 2007). Irrespective of the microeconomic models applied, the objective is to better understand the drivers of deforestation in relation to the net benefits derived from alternative forest uses (Sills and Pattanayak 2004). The conversion of forests to cropland and pasture has been identified as the main driver of deforestation in Africa (Rudel 2013). Agriculture and livestock systems are the dominant land-use types in southern Burkina Faso involving both indigenous and migrant groups. Converting forest to non-forest land uses incurs both costs and benefits, the benefits of which are expected to decrease over time as more forestland is brought under cultivation. On the other hand, the initial marginal net benefits of uncultivated forestland are nearly zero but increase with forest scarcity as more land is cleared for cotton and cereal production (Sills and Pattanayak 2004).

The current study was conducted in four villages adjacent to community forest areas in the Ziro province of southern Burkina Faso. Going by the justification of scale in relation to deforestation (Kaimowitz and Angelsen 1998, Gray 2010), only microeconomic models are applicable in this study. This does not mean that macroeconomic forces influencing tropical deforestation at various levels will not be considered. Microeconomic models have been used by economics to describe forest areas that have begun to reforest after years of deforestation (Angelsen 2007, Satake and Rudel 2007). The forest transition model thus represents a more convenient way for explaining land-cover change dynamics. The forest transition theory

(Mather 1992) also fits into the objective of this study, which is to assess the drivers of DD and options for revegetation. As such, the forest transition theory will be applied in combination with factors or variables that may introduce changes to stages II and IV of the forest transition curve, which this study refers to.

2.3. Forest transition theory

The forest transition theory was introduced by Mather (1992) to describe long-term changes in forest cover. According to this theory, agriculture is located on higher quality land with production expected to increase for a given period, which in turn releases and renders other land areas available for reforestation. Mather uses increasing agricultural adjustment of land quality to explain the dynamics of national forest areas that might result in either contraction or expansion. Aside from the spatial adjustment of agriculture to land quality, this theory agrees that other factors may also influence forest transition (Mather et al. 1998). As such, in addition to agricultural adjustment to land quality, other socioeconomic factors, such as crises, state interventions, population migration, and economic development, may influence forest transition (Angelsen 2007). Furthermore, forest transition may occur as a result of agricultural adjustment and concentration to more fertile land even without interventions related to forest policies.

Irrespective of the drivers at work, the focus of forest transition is to observe how a forested area experiences changes in forest cover from deforestation to regrowth. This may be portrayed as a u-shaped curve passing through a period of high deforestation and then reaching a turnaround point where forest cover stabilizes and eventually gives way to reforestation. The forest transition curve consists of four stages (see Fig. 2), which are driven by different factors, processes, and activities (Mather 1992). Stage I is characterized by low deforestation rates with relatively undisturbed and extensive forest stocks. The forest stock is perceived as unlimited and extraction occurs without any concern for future consequences. The inaccessibility of such areas for commercial production may provide unintentional and passive protection. Given the phytogeography of Burkina Faso, with the central and northern region affected by drought and desertification, forest cover is found in the southwestern region and is disturbed because of high land demand for agropastoral activities (Ouedraogo et al. 2015). The first stage of the transition curve is thus not applicable and was not considered a part of the current study.

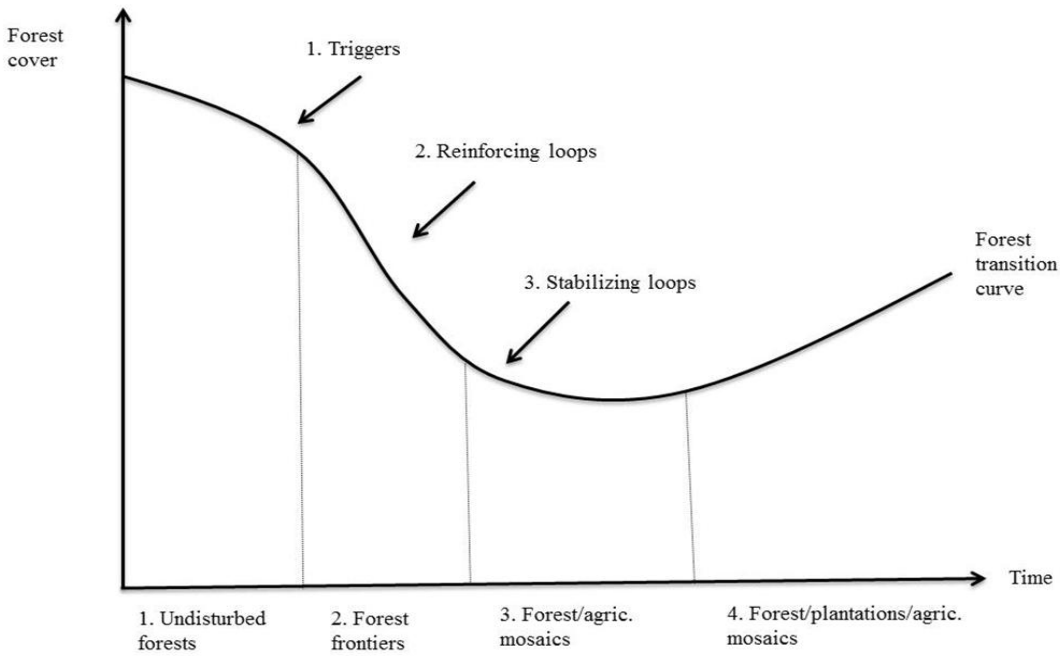

Figure 2. The four stages of the forest transition curve and its dynamics.
Adopted from Angelsen (2007).

However, improvement in infrastructure or economic development over time may create more access routes into the area that may lead to the second stage. Stage II experiences high deforestation rates, which may lead to forest scarcity as forest cover decreases. Migration in combination with agribusiness development has generated the highest deforestation rate in the southern region of Burkina Faso (Ouedraogo et al. 2009). Over 70% of the country is rural, and depends on agriculture and livestock for livelihood. Rural-rural migration to the southwestern region has led to land scarcity, land fragmentation, reduction of fallow areas, and field expansion into community forest areas (Reenberg et al. 2003). This trend of clearing the forest continues in stage II, until forest cover reaches an absolute minimum where resources are completely exhausted or some reforestation policies are implemented.

Stage III is the turnaround point where forest cover stabilizes due to a slowdown of deforestation. Unlike in stage I, society realizes that the resource is finite, and employs reforestation policies as deforestation is economically optimal and socially desirable. Forest product prices increase while demand decreases. Stage IV is a period of reforestation guided by the implementation of forestry policies that promote tree planting activities alongside sustainable forest management practices to increase forest cover. The explanation behind the increase in forest cover in China is linked to policies and interventions that promoted reforestation. The regreening process in the Sahel acknowledges community efforts in influencing revegetation on once-degraded areas in Niger (Sendzimir et al. 2011). Tree planting activities and the assisted natural regeneration of indigenous tree species in the parkland system have been identified as being responsible for the revegetation of the region. The government, private sector, and NGOs promote tree planting activities in Burkina Faso, where seedlings are provided to farmer groups at reduced prices (Etongo et al. 2015).

Despite the opportunity for indigenous tree species to regenerate naturally, other factors influence farmers to endorse ANR. A study in the Sahel showed that ANR improved farmers' security to the land (Weston et al. 2015). Land in Burkina Faso is governed by customary laws while access to land is granted by land chiefs. An inheritance system is common among the indigenous groups in which land belonging to each family is shared between males. Land chiefs assign a portion of the land to migrant groups in exchange for gifts. Migrants are considered borrowers because of their limited land-use rights that can only become permanent after a century of occupancy (Ouedraogo 2006). Improving the land is considered a form of ownership and tenure insecurity has been found to affect not only tree planting activities but assisted natural regeneration also. In addition, tenure insecurity is likely to affect land management practices such as fallow, life hedges, and the Zai practice that have been shown to improve both soils and tree cover (Kaboré and Reij 2004).

2.4. Overall study framework

This study concentrates on aspects found within the box of Fig. 3. These factors interact among themselves, creating an environment in which the agent's decision and land-use practices may lead to DD or regrowth/revegetation. More specifically, the study addresses issues in stages II (the forest frontier, which experiences higher deforestation rates) and IV (forest/plantations or agricultural mosaic landscapes) of the forest transition curve. Studies I and II are therefore linked to the second stage of forest transition while Study III and IV are linked to the fourth stage of the forest transition curve (Fig. 2). To understand the drivers of deforestation at the farm/forest level, emphasis was placed on land tenure insecurity and household assets (study I), while forest degradation considered household poverty in relation to land access and the adoption of practices considered environmentally degrading (Study II).

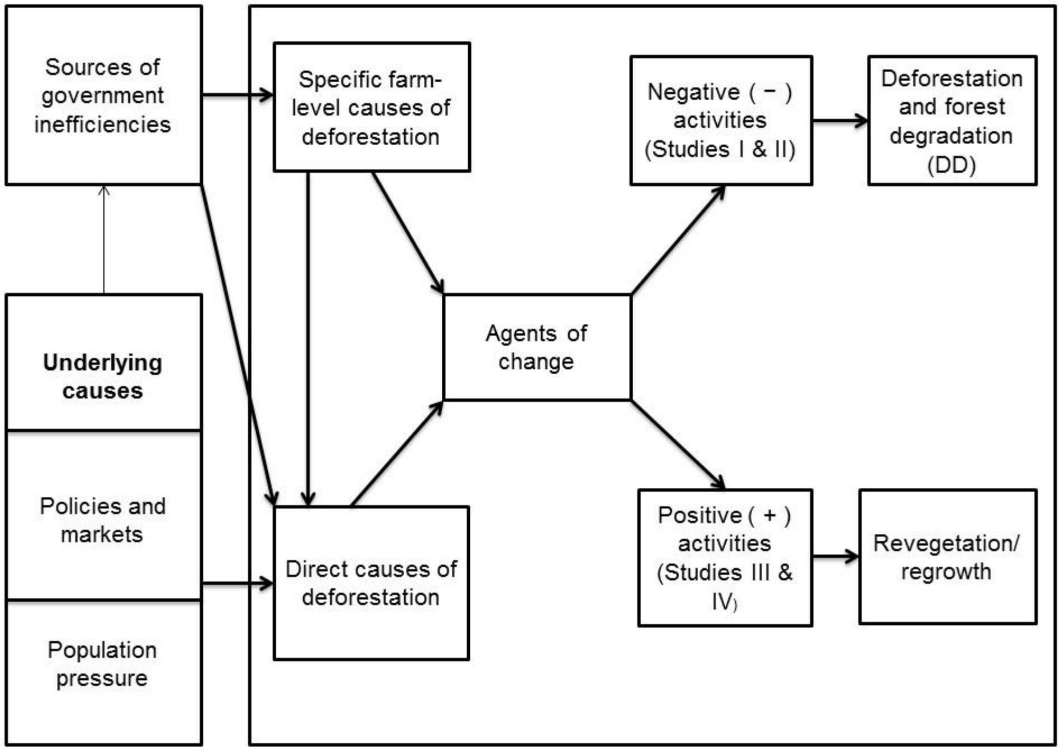

Figure 3: Schematic diagram of the study focusing on the issues inside the box.

Studies III and IV address smallholder tree planting activities and tree knowledge for livelihood values and their potential for environmental protection. Assisted natural regeneration is also considered an important land management practice that promotes regrowth and improves tree cover. This aspect is considered in detail in study II, where three wealth groups are assessed in relation to their land management practices to identify the group most responsible for environmentally degrading activities. However, DD and regrowth/revegetation are simultaneously ongoing activities in Burkina Faso. A recent study in the southern region of Burkina Faso indicated forest loss between 1986 and 2002 while forest cover was gained between 2002 and 2006 (Ouedraogo et al. 2010). The forest transition theory is therefore applicable in the current study.

3. Materials and methods

This study uses both qualitative and quantitative research methods as they complement each other and provide a better understanding of possible resource use strategies. Qualitative methods capture issues that are socially and politically constructed and investigate how people shape their environment (Merriam 1998). As Patton (1990) explains:" qualitative research is an effort to understand situations in their uniqueness as part of a particular context and interaction so that it is not attempting to predict what may happen in the future necessarily but to understand the nature of that setting…" Because qualitative data cannot provide precise measurements, quantitative methods were also applied in this study. This was achieved through the construction of statistical models to explain what was observed.

The methods of data collection included interviews with key informants, focus group discussions (FGDs), the administration of semi-structured questionnaires, and a field survey. Given that less than 50% of the community members can communicate in French, the role of the research assistant was invaluable. The research assistant spoke two of the local languages including Mòoré, which is spoken in approximately 70 of the village communities. In addition, the research assistant has been working on livelihood issues in the region, and therefore understood the questionnaires with little explanation. Approximately 40% of the 200 household interviews were conducted in Mòoré during which the role of the research assistant was invaluable. The questions were posed in Mòoré to those who cannot communicate in French. Responses were given in Mòoré, which was then translated into French by the research assistant to be recorded by the researcher.

Youth leaders are local authorities in the villages and their role during data collection was to introduce the researcher and his assistant to the interviewees in each of the visited households. In relation to the region's culture, the presence of the youth leaders is considered a form of acceptance for the conduction of the interviews. The qualitative data sets were analyzed using descriptive statistics while quantitative data were analyzed using ANOVA, the Tobit model, and the Multiple Schiff test. A detailed methodology for each study can be found in the original papers that constitute this dissertation.

3.1. Study sites

The study sites are located in four adjacent forest communities (Fig. 4) in the Ziro province of southern Burkina Faso (11° 16' N to 11° 45' N and -2° 10' W to -1° 48' W). This province covers 5291 km^2 and is characterized by low-relief topography with a mean altitude of 300 m above sea level. Phytogeographically this region is located within the south-Sudanian ecological zone (Fontes and Guinko 1995) and receives the highest amount of rainfall in the country, ranging from 800 mm to 1000 mm annually. Rainfall follows a unimodal pattern that lasts for six months (May to October). The main soil types are silt-clay cambisols, sandy lixisols, and loamy ferric luvisols (Driessen et al. 2001). These villages were selected under the framework of the program 'Sustainable Rural Development through High Value Biocarbon Approaches: Building Multifunctional Landscapes and Institutions in West Africa (BIODEV)'.

The average population density is estimated at 28 inhabitants/km² across the 30 villages in the province (INSD 2007), with 34.7 inhabitants/km² in Cassou (Ouedraogo et al. 2015). This figure represent the highest population density in Burkina Faso. The outcome of such densities is the combined effect of natural increase and rural-rural migration from the north and central region to the southwestern region. This is caused by the geographical setting of Burkina Faso, which exposes the central and northern regions to drought and desertification. On the other hand, the southwestern region offers better opportunities for rain-fed agriculture, year-round fodder supply, fuelwood from community forest areas, and forest products. For the last thirty years these opportunities have acted as pull factors for the Fulani and Mossi ethnic groups from the north and central regions migrating to the southern region (Henry et al. 2003, Ouedraogo et al. 2009, 2015).

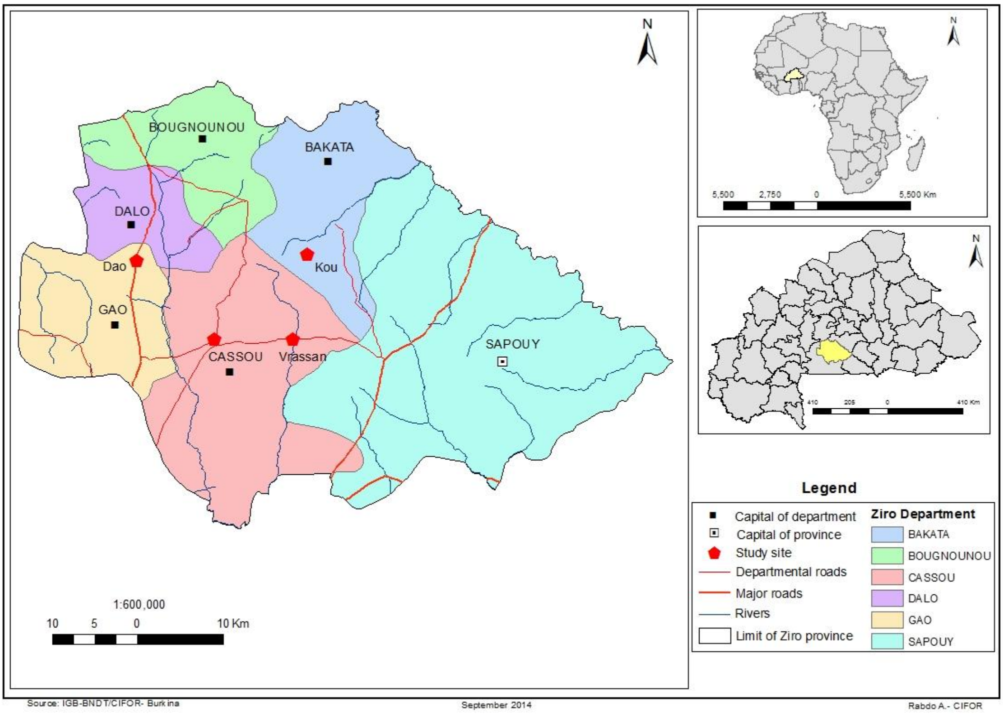

Figure 4. Map showing the study sites

The dominant farming system in this region is the traditional cultivation of cereals (e.g. sorghum, millet, sesame, and maize) and tubers (yam and sweet potatoes), cotton, and livestock herding (Paré et al. 2008). In fact, the Sahelian landscape is dominated by agropastoral systems that constitute a source of livelihood for over 70% of the population (FIP 2012). The shift in attention to cash crop production (cotton and cashew nut) and the development of ranches have created intense land-use competition at the detriment of traditional farming systems, which have persisted for centuries (Paré et al. 2008, Ouedraogo et al. 2010). Community forests were created in this region to ensure a sustainable wood energy supplies to the nearby cities of Ouagadougou and Koudougou (Thieba 2003, Coulibaly-Lingani et al. 2011). Community forests provide commercial fuelwood and construction poles in addition to other forest products. Such benefits attained from the forest not only provide income but additionally diversify livelihoods: a coping strategy for adapting to climate change.

In the parkland system, indigenous tree species are deliberately spared from felling during cultivation. Crops are grown under the discontinuous cover of scattered trees that reflect the ecological knowledge of farmers in such a risk-prone environment. The occurrence of tree species such as *Vitellaria paradoxa* C.F. Gaertn, *Parkia biglobosa* (Jacq.) R. Br. ex G. Don., and *Tamarindus indica* L., are a common feature of the parkland system. The flora is dominated by perennial grass such as *Andropogon gayanus* Kunth, A. ascinodis C.B. Clarke and *Schizachyrium sanguineum* (Retz.) Alston (Fontes and Guinko 1995).

Forests in Burkina Faso are under two alternative management regimes: protected and classified, and over 70% of the country's forest are found in the southwestern region. Classified forests (25%) incorporate parks that are strictly protected from livestock and farming while protected forests are community-managed forests including village forests (Kambire et al., 2015). The difference between community-managed and village forests is that the government collaborates with the community in the management of the former, while no collaboration exists in the latter and the sole responsibility in decision-making and management rests completely on the communities.

3.2. Methods

3.2.1. The effects of tenure insecurity and household assets on deforestation (study I)

This study was conducted at the following four sites: Cassou, Vrassan, Dao, and Kou (see Fig. 4). Three ethnic groups live in this region and include the Gourounsi (indigenous group), Fulani, and Mossi (migrant groups originating from the north and central region). Two hundred household interviews incorporating all three ethnic groups were conducted using stratified random sampling techniques. A total of 24 out of 200 respondents were randomly selected from the three ethnic groups to survey their fields. The purpose of the field survey was to confirm the interview data such as estimated farm sizes, fallow area, field expansion into forests, and ongoing land management practices.

Tobit Maximum Likelihood Estimation (MLE) was used in this study because the collected data proved that some smallholder farmers clear forestland for agriculture and livestock while others do not. The dependent variable is the mean annual area of cleared forest per year over a ten-year period (2003–2013). Jones et al. (1995) applied a similar method and hypothesized that larger annual clearance rates and longer ownership of farms would produce larger stocks of cleared land. The model adopted for this study measures the probability of forest clearance and its intensity in relation to households. The distribution of the dependent variable thus does not follow normal distribution. The Ordinary Least Squares (OLS) method does not fit because the distribution of the observed values is not assumed to be linear, and the standard Tobit model (Tobin 1958) is therefore applied as follows:

$$yi = \alpha + Xi\beta + \varepsilon i, \quad i = 1, 2, \ldots, n, \tag{1}$$

where yi is a latent response variable, Xi is an observed $1 \times k$ vector of explanatory variables, n is the number of observations, εi is the error term assumed to be independent and normally distributed with $N(0, \sigma^2)$, and β is a vector of unknown coefficient parameters to be estimated.

The observed dependent variable (Yi) was calculated by finding the difference in farm area between 2003(ha) and 2013(ha)/10 to get the annual mean rate of deforestation as follows: mean annual deforestation (MAD) = Farm area in 2013 (without fallow) – farm area in 2003 (without fallow)/10.

Assuming that Yi is obtained when $yi > 0$ but is not observed when $yi \leq 0$ (where yi is the latent dependent variable). Then the observed Yi *in* our model will be specifically defined as:

$$Yi = \begin{cases} yi \text{ if } yi > 0, \\ 0 \text{ if } yi \leq 0 \end{cases} \tag{2}$$

3.2.2. Poverty and environmental degradation (study II)

This study was conducted using different methods of data collection such as key informants, FGDs, household interviews, and a field survey across the four study sites (Fig. 3). A key informant (in our study the youth leader of the village) was contacted in each village to identify five suitable participants for the FGD. The selected participants had to satisfy two conditions: (i) must have lived in the community for at least ten years, (ii) represent as much as possible a wide cross-section of the community. In this case, the "sub-chiefs" of the ethnic groups and women leaders were considered. The aim of the FGD was to develop a poverty profile for the study area through a participatory exercise.

The FGD participants were asked the following question: (i) to list the indicators used locally to assess wealth status, (ii) to describe the specification of each local indicator and how they relate to its corresponding income group (Narayan et al. 2000). Secondly, activities/indicators related to environmental degradation were discussed, including cotton cultivation, farm age and size, fuelwood extraction, overgrazing, soil fertility loss, lack of fallow, tenure insecurity, and field expansion. Rather than the money metric criteria for assessing poverty, the livelihood approach in relation to household assets was applied (Booysen et al. 2008). Community members define their wealth criteria and classify themselves based on locally generated indicators (Howe and Mckay 2007).

The indicators across the villages did not differ significantly. FGD participants agreed on a common list of 12 local indicators and their descriptions with a detailed explanation pertaining to each indicator (Table 1). The wealth categories identified in the villages were as follows: Cassou (rich, fairly rich, poor, and poorest), Dao and Kou (rich, fairly rich, and poor), and Vrassan (rich and poor). To attain a unified system of ranking, Ravnborg et al.

(1999) used the mean value to even out such differences. We adopted this system in our study in the following way: (4+3+3+2)/4 = 3. This gave three qualitative wealth groups that were quantified following Ravnborg et al. (1999) as:

$$S = (A-1)/(P-1) * 100 \quad (1)$$

Table 1. Household poverty indicators and scoring system in southern Burkina Faso

Indicator	Score	Description
Access to land	0	Owns more than 10 ha of land
	50	Owns between 4 to 10 ha of land
	100	Owns less than 4 ha of land
Food security	0	Household without a period of food shortage in the last 3 years
	50	Experienced a food shortage lasting < 3 months in the last 3 years
	100	Experienced a food shortage lasting > 3 months in the last 3 years
Healthcare	0	Capable of paying for medical services in the district hospital and beyond
	50	Capable of paying for medical services limited to the district hospital
	100	Unable to pay for medical services and reliance on herbal medicines
Non-agricultural income sources	0	Receives income from the sale of livestock, shops, owns a truck for transportation
	50	Uses cart to transport crops for income, sells food and NTFPs
	100	Household does not have any other source of non-agricultural income
Sale of crops	0	Sells more than half of the cereals produced while satisfying household needs
	50	Selling up to half of the cereals produced will lead to a food shortage
	100	Does not sell cereals and is not self-sufficient. Depends heavily on NTFPs
Agricultural equipment	0	Cultivates the land with tractor and draught ox. Own compost-production facilities
	50	Cultivates with donkeys and is capable of buying compost to use on farm
	100	Cultivates land with hand hoes and cutlasses
Tree resources	0	Owns tree plantations (fruit trees, poles for construction, etc.)
	50	Has a few trees on farm and around compound for subsistence and commercial use
	100	Does not own trees on farm and compound but depends on forest for NTFPs
Livestock ownership	0	Owns three or more herds of cattle (a herd is 10 cows)
	50	Owns less than three herds of cattle
	100	Does not own any cattle
Ownership of other animals	0	Owns three droves of donkeys, goats and sheep (a drove is 10 animals)
	50	Owns less than three droves of donkeys, goats and sheep
	100	Does not own any donkeys, goats, or sheep
Household appliances	0	Owns TV/Solar panel, radio/radio-cassette player and Yamaha generator
	50	Owns radio/radio-cassette player, uses motor battery to generate electricity
	100	Does not own electrical appliances but uses kerosene lamp
Transportation	0	Owns ≥ 1 car and ≥ 1 motorcycle
	50	Owns a motorcycle and cart
	100	Owns a bicycle and other members of household often travel on foot
Institutional credit	0	Has the required collateral security for credit and is capable of paying back
	50	Limited collateral to credit and might be unable to pay if externalities arises
	100	Lacks collateral for credit and also lacks the potential for repayment

Where S = Well-being score, A = the well-being categories that various households in the communities were assigned to, and P = the total number of well-being categories. Results were multiplied by 100 to avoid operating with decimals, resulting in:

Level 1- [(1-1)/ (3-1)] * 100 = 0, where 0 implies **non-poor** household

Level 2- [(2-1)/ (3-1)] * 100 = 50, where 50 implies **fairly poor** household

Level 3- [(3-1)/ (3-1)] * 100 = 100, where 100 implies **poorest** household

3.2.3. Smallholder tree planting activity (study III)

This study was conducted in same study sites as studies I and II and the entry point was contact with key informants. The purpose was to identify and contact participants for the FGDs, such as tree growers, land chiefs, members of farmer or forest management group (FMG), and a representative from the Gourounsi, Mossi, and Fulani ethnic groups found in the region. The aim of the FGDs was for participants to provide information on tree species planted in the region, previous or ongoing tree planting projects, and local perceptions of tree planting in relation to socioeconomic and institutional factors such as markets, tenure insecurity, extension services from the government, and training concerning tree management. A research assistant who understood and spoke the local language led the discussion on tree planting in the region. A total of ten tree species were mentioned and those planted by ≤ 10 farmers were left out. A study in sub-Saharan Africa on farmers' tree planting practices (Ræbild et al. 2004) applied this method and we also adopted it for this study.

Based on the above criteria, six of the ten species were retained and include *Adansonia digitata* L., *Anacardium occidentale* L., *Azadirachta indica* A. Juss., *Eucalyptus camaldulensis* Dehn., *Mangifera indica* L., and *Moringa oleifera* Lam. The criteria for selecting respondents for the interviews were twofold: (i) farm size should be ≥ 2 ha and (ii) farmer must have planted or is currently managing at least one of the six species. An equal sample size of 50 smallholders was selected in each of the four villages, giving a total of 200 respondents. Based on the six selected species, close-ended questionnaires were designed to collect information on farmers' socioeconomic characteristics, farm characteristics, tenure arrangements, silvicultural practices, and local perceptions of tree planting. These variables were modified from existing literature to suit the aims of our study (Emtage and Suh 2004, Kallio et al. 2011).

3.2.4. Relative importance of trees for livelihoods and their potentials for environmental protection (study IV)

This study was carried out in three of the four studies sites: Cassou, Dao, and Kou. The Ecological Apparency Hypothesis (EAH) assumes that the higher the availability of a plant, the higher its use value. (de Lucena et al. 2012). Information gathered from previous studies in Burkina Faso (Kristensen and Lykke 2003, Paré et al. 2010) and FGDs resulted in a list of the 30 most-exploited plant species in the region. An inventory was conducted in 135 plots of

0.5 ha in size to document species diversity in the region. Furthermore, specimens were identified and collected during the inventory and attached to an exercise book (see Figure 5 below).

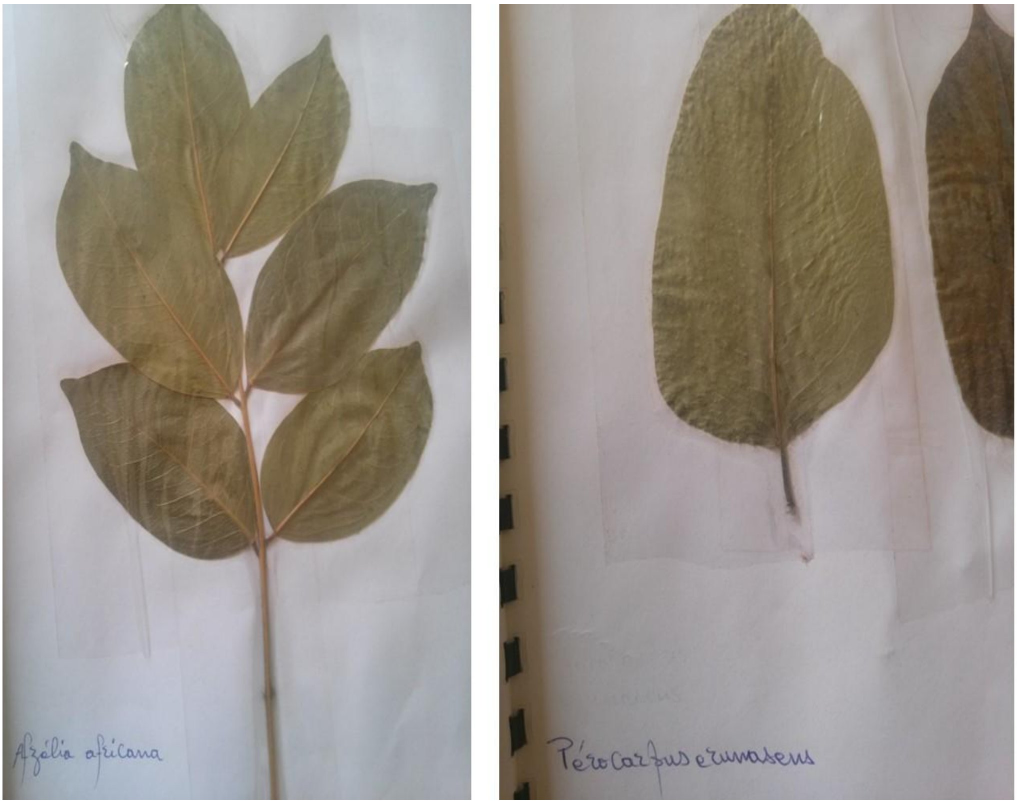

Figure 5. Samples of collected tree specimen used for assessing ethnobotanical knowledge

With the assistance of village youth leaders, a total of 48 informants in an uneven age group distribution were selected from the Gourounsi, Mossi, and Fulani ethnic groups in the three villages. The reason for such a selection is because botanical knowledge is unevenly distributed across age groups, gender, profession, location, and ethnic groups (Hanazaki et al. 2000, Dovie et al. 2008). Semi-structured questionnaires were used and the respondents were asked the following questions: (i) to identify each plant species based on the specimens provided, (ii) to mention all the uses known for each of the 30 species in the following categories: food, fodder, wood fuel, medicine, income, construction, crafts, and other uses, and (iii) to mention species that have the potential to protect the environment e.g. through soil improvement, erosion control, and wind and fire damage prevention.

Each of the 48 respondents was interviewed twice on separate days and the interviews lasted from one to two hours. The use-value method devised by Phillips and Gentry (1993), and modified by Rossato et al. (1999) and Silva and Albuquerque (2004), was applied in this study as follows:

Relative use-values across categories;

$$UV = \sum Ui/n$$

where: U_i = the number of uses mentioned by each informant for a given species and
n = the total number of informants

Relative use-values within a category;

The importance of a given tree species for specific uses was recorded based on a scoring system ranging from 0–3. The basic assumption was that a very useful and preferred species was given a score of 3, useful species were assigned a value of 2, while the value 1 was assigned to species considered good but only used occasionally, while species considered of low quality was assigned a value of 0. For example, a 0 was assigned to fruits only eaten occasionally in fields. A higher rating was assigned when informants indicated a tree species as preferred or one of the best. The values of 0, 1, 2, and 3 (rather than 0.5, 1.0, and 1.5, or other alternatives) were solely used to provide use-values comparable to those of Phillips and Gentry (1993). The method for calculating use-values within use-categories is shown below (Table 2), using *Parkia biglobosa* as an example.

Table 2. Respondent-level use-values within categories for *Parkia biglobosa*

	No. of Informants/score				Sum	Average use-values
Use categories	**3**	**2**	**1**	**0**		
Food	39	7	2	0	133	2.77
Fodder	2	2	38	6	55	1.11
Woodfuel	5	10	24	9	59	1.22
Medicine	41	0	7	0	156	3.25
Income	10	25	1	12	81	1.68
Construction	5	10	7	26	42	0.88
Crafts	5	10	6	27	41	0.86
Others	25	5	15	3	100	2.09
Total use-value						13.86

4. Results

4.1. The role of tenure insecurity and asset holdings on deforestation (I)

This study shows that migration status is a proxy for tenure security due to limited usage rights granted to these groups. A total of 54 percent of the 200 respondents had unsecured land tenure and were exclusively migrant farmers (Fig. 6). The migrants consist of two ethnic groups: the Fulani and the Mossi, originating from the north and central plateau of Burkina Faso. Apart from tenure insecurity, migrants are considered borrowers and access land in two ways: (i) through sharecropping or fixed-term land leasing. This form of access is common on family-owned lands. (ii) Community lands granted to migrants. Such usage agreements are either renewable or have no time limits provided local customs and rules are observed. On the other hand, the inheritance system is the main form of land access for the indigenous groups. Over 40 percent of the 200 respondents access land through the inheritance system, while an estimated 5 percent had access to land through sharecropping (Fig. 7).

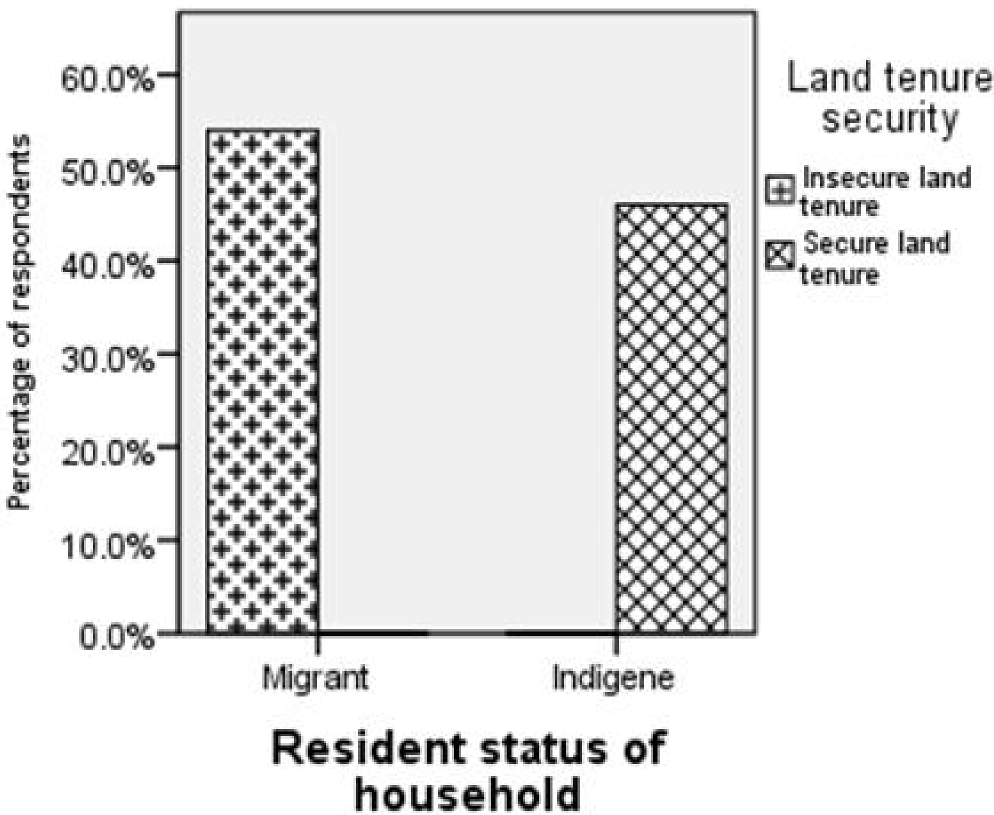

Figure 6. Migration status as a proxy for tenure security

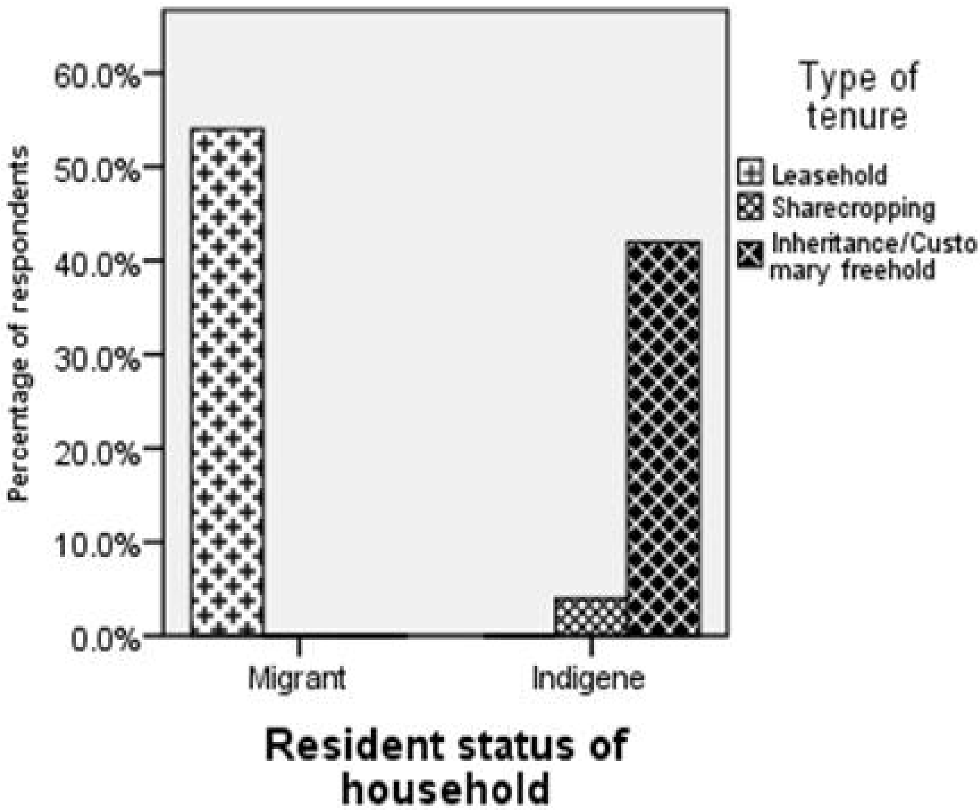

Figure 7. Residential status and different forms of land access

In this study, annual deforestation is significantly influenced by low farm productivity and tenure insecurity at the 1 percent level of significance. Farm area and age are two different variables associated with low farm productivity. Results reveal that a 10 percent increase in farm area will induce a 4 percent annual deforestation (Table 3). Such a result suggests that agricultural expansion into forest areas represent a major driver of deforestation. Furthermore, farms that were 10 percent older were associated with an annual deforestation rate less than 2 percent, compared to farms that have been recently established. In relation to tenure security, annual deforestation was 3 percent lower for farmers with secure land tenure compared to those with insecure land tenure. Household income per hectare additionally affects annual deforestation at a marginal level of significance. A 10 percent increase in income per hectare would result in a 0.1 percent units increase in annual deforestation.

Table 3. Results of Tobit regression analysis

Tobit regression						Number of obs. = 200
						LR chi2(12) = 151.35
						Prob > chi2 = 0.0000
Log likelihood = -56.784378						Pseudo R2 = 0.5713
AnnualDeforestation	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Age	-0.0006718	0.002215	-0.3	0.762	-0.0050417	0.003698
FuelwoodconsumpMonthly	0.0160363	0.043428	0.37	0.712	-0.0696334	0.101706
logHHsize	-0.047789	0.073271	-0.65	0.515	-0.1923285	0.0967505
logFsize	0.4196381	0.045977	9.13	0.000***	0.3289415	0.5103347
logNumberoffarms	0.018859	0.048311	0.39	0.697	-0.076443	0.1141611
logFage	-0.2443207	0.049047	-4.98	0.000***	-0.3410745	-0.1475669
logDistanceToForest	-0.0413452	0.042303	-0.98	0.330	-0.124795	0.0421046
logPerHa_NetAnnInc2013	0.0112525	0.006012	1.87	0.063*	-0.0006071	0.0231121
logCattle	-0.0192218	0.031492	-0.61	0.542	-0.0813443	0.0429006
logSmallRumin	-0.0143092	0.02778	-0.52	0.607	-0.0691102	0.0404917
1.HHheadEduc (i)	-0.0873214	0.07031	-1.24	0.216	-0.2260195	0.0513767
1.LandTen (i)	-0.2965744	0.056589	-5.24	0.000***	-0.4082056	-0.1849432
_cons	0.4478562	0.134194	3.34	0.001***	0.1831363	0.712576
/sigma	0.275575	0.018315			0.2394463	0.3117037
	74 left-censored observations at AnnualDeforestation<=0					
Obs. summary:	126 uncensored observations					
	0 right-censored observations					

(i): These are ordinal independent variables that were introduced in the Stata model as categorical variables; the Reference category is their first level (modality = 0). Their coefficients are therefore interpreted with regard to the reference modality.

4.2. Poverty and environmental degradation: is there a link? (II)

Using PPA methods the smallholder farmers in the four study villages were classified into three income categories: the non-poor, fairly poor, and poorest. The results indicated that all the indicators of environmental degradation showed a statistical significance at the 5 percent level among the wealth categories (Table 4). Therefore, each wealth category exhibited a different mean for each indicator of environmental degradation.

Table 4. Environmental degrading activities and its relation across poverty levels

Indicators of environmental degradation		Wealth categories of households (%)			Total (%)	Chi-Square Tests		
		Non-poor	Fairly poor	Poorest		Value	Df	Asymp. Sig. (2-sided)
Derived categorical forms from our quantitative collected variables								
Deforestation 2003-2013	No	1.00	19.50	16.50	37.00	18.30	2	0.000
	Yes	15.00	32.00	16.00	63.00			
Cotton cultivation	No	13.00	30.50	25.50	69.00	9.57	2	0.008
	Yes	3.00	21.00	7.00	31.00			
Cutting and selling fuel wood	No	14.50	27.00	19.50	61.00	15.01	2	0.001
	Yes	1.50	24.50	13.00	39.00			
Overgrazing	No	0.00	19.00	27.00	46.00	66.67	2	0.000
	Yes	16.00	32.50	5.50	54.00			
Farmers' self-reported assessment								
Overgrazing (Farmers' assessments of overgrazing on their own farms)	Low	0.0%	42.7%	84.6%	49.5%	110.259	4	0.000
	Moderate	6.3%	32.0%	15.4%	22.5%			
	High	93.8%	25.2%	0.0%	28.0%			
Soil fertility loss (Farmers' assessment of soil fertility loss on their own farm)	Low	65.6%	49.5%	27.7%	45.0%	42.191	4	0.000
	Moderate	28.1%	23.3%	6.2%	18.5%			
	High	6.3%	27.2%	66.2%	36.5%			
Tenure insecurity (Farmers' assessment of the effect of tenure insecurity on FMNR)	No FMNR	100.0%	51.5%	35.4 %	54.0%	36.595	2	0.000
	Yes FMNR	0.0%	48.5%	64.6%	46.0%			

In addition, the statistical results reveal that 63 percent of the respondents expanded their fields into forest areas or cleared new farmland between the years 2003 to 2013 while 37 percent did not (Table 4). The newly cultivated areas during the ten-year period are significant for the non-poor at the 5% level. Human migration and field expansion are two possible explanations for the establishment of new farms. Furthermore, thirty-one percent of the farmers interviewed cultivated cotton while 69 percent did not. Cotton cultivation is capital-intensive and requires animal traction, which limits the effective participation of the poorest farmers. In addition, agricultural poisoning in the region was identified as a common problem that is attributed to the use of pesticides for the treatment of cotton. During one of our field visits in Vrassan village in January 2014, approximately eight cattle were found dead and many affected. Furthermore, cutting and selling fuelwood is another activity considered environmentally degrading. Non-poor farmers cut and sell larger quantities of fuelwood followed by the fairly poor and the poorest, because non-poor farmers have more resources for hiring labor and for transportation.

Farmers' self-reported assessment reveals that, tenure insecurity hinders non-poor farmers from participating in the assisted natural regeneration of indigenous tree species (Table 4). Given that FMNR is considered to improve the environment by increasing tree biomass and diversity, farmers not engaged in such practices are considered to degrade the environment. This is because indigenous trees form an important component in the Sahel known as parkland systems, which have persisted for centuries (Bayala et al. 2014). On the other hand, the adoption of land management practices considered to improve the environment was relatively low among the poorest farmers compared to the non-poor and fairly poor (Fig. 8). However, while the non-poor and fairly poor households contributed more towards activities considered environmentally degrading, the poorest on the other hand cannot effectively implement certain land management practices considered to protect the environment.

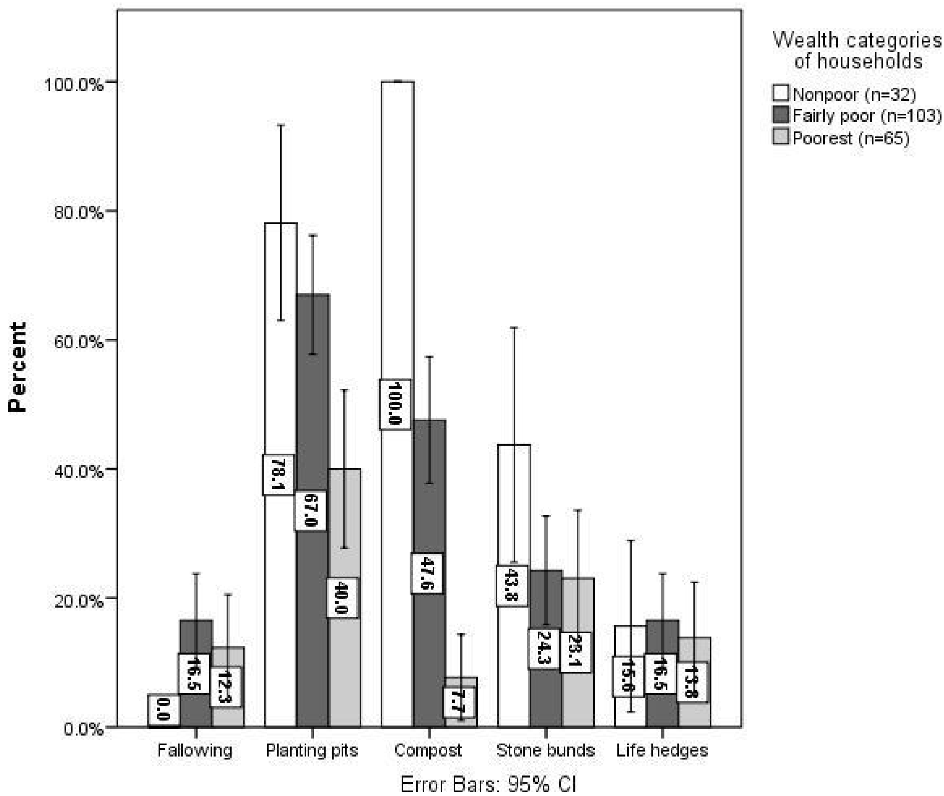

Figure 8. Land management practices adopted by respondents across wealth categories

4.3. Smallholder tree planting activity (III)

The number of planted or currently managed trees differs among species and across the four villages (Table 5). Cassou village had the highest number of planted trees owing to its long history of development projects and interventions by the government and development agencies. Aside from the planted or currently managed trees in the study villages, tree planters and non-tree planters differed significantly in socioeconomic characteristics. Tree planters mainly owned older and larger farm areas, were literate and relatively wealthy, held a favorable attitude towards tree planting, and had participated in farmer groups for a considerable number of years.

Table 5. Number of trees currently planted or managed

Total number of trees classified by genera, currently planted/managed at the study sites								
Study sites	**Adansonia**	**Anacardium**	**Eucalyptus**	**Moringa**	**Mangifera**	**Azadirachta**	**Total**	**%**
Cassou	85	726	1476	336	411	70	3104	47
Vrassan	21	280	640	140	441	52	1574	24
Dao	2	291	193	108	182	18	794	12
Kou	22	313	304	147	278	68	1132	17
Total	130	1610	2613	731	1312	208	6604	-
%	2	24	40	11	20	3	-	100
Average number of trees currently planted/managed at the household level								
Sample's Mean	0.65	8.05	13.07	3.66	6.56	1.04	33.04	-
Std. Dev	2.27	16.47	45.81	6.60	10.46	3.09	75.41	-
Min.	0	0	0	0	0	0	0	-
Max.	15	100	350	30	50	16	545	-

Where (−) implies 'not applicable' and Std. Dev. means 'Standard Deviation'

Farmers indicated several reasons for planting trees, but the main reasons were economic, including income generated through the sales of wood, fruit, and other products derived from trees. Furthermore, markets for certain tree species and support from projects either through free or reduced-price seedlings were mentioned as motivation for tree planting. For example, Figure 9 shows an ongoing tree planting project in Cassou village in 2013. On the other hand, the main reasons mentioned by smallholders for not participating in tree planting include a preference for agriculture, tenure insecurity, and lack of sufficient land (Table 6).

Figure 9. Tree nursery of *Moringa oleifera* (**A**) and *Adansonia digitate* (**B**) in Cassou.

The previous or planned use of income received from wood and tree products was mostly used for daily consumption. Seventy-five, 65, and 50 percent of respondents in this category planted *Moringa oleifera, Mangifera indica,* and *Anacardium occidentale,* respectively. The percentages were very low for *Adansonia digitata*, *Eucalyptus camaldulensis*, and *Azadirachta indica,* with approximately 10 percent of respondents indicating income from these trees as being used for daily consumption. In terms of anticipated expenditures, more than 60 percent of respondents cited *Azadirachta indica* while *Adansonia digitata* and *Eucalyptus camaldulensis* were cited fairly as often (approximately 50 percent of respondents for each species). The number of respondents who mention the use of income from *Anacardium occidentale*, *Moringa oleifera*, and *Mangifera indica* for anticipated expenditures were less than 40 percent. The figures were relatively low for respondents who considered the use of income from wood and tree products for unexpected expenditures. For the entire six tree species considered in this study, none had more than 40 percent of respondents in this category.

Table 6. Farmers' reasons for **(a)** planting trees and **(b)** not planting trees

	***Adansonia digitata* (%)**	***Anacardium occidentale* (%)**	***Eucalyptus camaldulensis* (%)**	***Moringa oleifera* (%)**	***Mangifera indica* (%)**	***Azadirachta indica* (%)**	**Average (%)**
				a) Reasons for planting trees			
Economic (income/investment)	22	55	70	40	82	11	46.7
Building material	0	0	50	0	0	15	10.8
Fuelwood	4	0	28	0	0	20	8.7
Incentives	20	50	6	30	4	2	18.7
Market access	6	18	60	35	45	10	29
Support for tree planting	30	30	5	55	4	2	21
Environmental reason (Erosion control, greening,	15	0	2	20	8	8	8.8
For land security	0	0	0	0	0	0	0
Low labor requirements	0	45	3	16	20	5	14.8
				b) Reasons for not planting trees			
Insufficient amounts of land	45	20	5	2	38	4	19
Lack of seedlings/higher prices for seedlings	20	35	14	10	2	12	15.5
Farmer prefers agriculture	50	15	50	16	22	35	31.3
Not profitable (low prices)	28	25	5	2	6	20	14.3
Lack of markets	15	45	3	25	10	40	23
Longer rotation period	40	10	20	4	12	18	17.3
Health problems	0	0	0	0	0	0	0
No time/labor	0	2	6	1	0	2	1.8
Unsuitable land	0	0	25	0	0	14	6.5
Lack management knowledge of trees	10	3	2	2	0	15	5.3
Newcomer in the village	0	1	0	4	2	0	1.2
Lack tenure security for land and trees	30	22	35	28	12	20	24.5

Remark (a): Farmers could mention several reasons for planting trees. Data from *Adansonia* planters (n=23) and non-planters (n=177), *Anacardium* planters (n=64) and non-planters (n=136), *Eucalyptus* planters (n=34) and non-planters (n=166), *Moringa* planters (n=59) and non-planters (n=141), *Mangifera* planters (n=100) and non-planters (n=100), and *Azadirachta* planters (n=25) and non-planters (n=175).

Farmers' willingness to continue tree planting also differed with household socioeconomic characteristics and between the different tree planters. Poor households in addition to households with smaller workforces, smaller farm areas, and tenure insecurity (24.5%) were not willing to continue tree planting. In terms of tree species, 32 percent of *Anacardium occidentale*, 15 percent of *Eucalyptus camaldulensis*, and 32 percent of *Azadirachta indica* planters were unwilling to continue tree planting.

4.4. Relative importance of trees for livelihood values and environmental protection (IV)

Study IV focuses on the relative importance of 30 selected tree species for livelihood values and their potentials for environmental protection in relation to their use-values. Based on the use-value method, the following species dominated each of the eight categories as follows (Fig. 10): food (*Vitellaria paradoxa*, *Adansonia digitata*, and *Parkia biglobosa*), fodder (*Balanites aegyptiaca*, *Adansonia digitata*, and *Vitellaria paradoxa*), woodfuel (*Adansonia digitata*, *Parkia biglobosa*, and *Vitellaria paradoxa*), medicine (*Adansonia digitata*, *Vitellaria paradoxa*, and *Daniella oliveri*), income (*Parkia biglobosa*, *Afzelia africana,* and *Adansonia digitata*), construction (*Pterocarpus erinaceus*, *Azadirachta indica*, and *Diospyros mespiliformis*), craft (*Balanites aegyptiaca*, *Afzelia africana*, and *Ficus sycomorus*), and potential for environmental protection (*Adansonia digitata*, *Parkia biglobosa*, and *Vitellaria paradoxa*).

The overall use-values indicated that *Adansonia digitata*, *Vitellaria paradoxa*, *Parkia biglobosa*, *Ficus sycomorus*, *Afzelia africana*, *Diospyros mespiliformis*, *Azadirachta indica*, and *Daniellia oliveri* were considered more useful than other species. The variation in botanical knowledge is additionally significant at the 0.01 percent level across age, gender, ethnicity, and location (Table 7 and 8). The elderly age group had more knowledge on plant uses because local plant knowledge accumulates over time and is influenced by farmer activity. Contrary to the commonly observed pattern of women being more knowledgeable than men regarding plant uses, the reverse was observed in this study. Limiting this study to thirty selected species may be the reason for this deviation. Botanical knowledge was additionally slightly higher for the Gourounsi ethnic group than other groups while villagers of Kou, which is more remote, had more knowledge on plant uses.

In accordance with the International Union for Conservation of Nature (IUCN) classification, 80 percent of the 30 selected species have not been evaluated, 10 percent are vulnerable, 6.7 percent are of least concern while 3.3 percent are data deficient. The vulnerable species includes *Afzelia africana*, *Khaya senegalensis*, and *Vitellaria paradoxa*. This classification sets a standard but does not imply that other knowledge systems are unimportant. For example, the environmental protection potential of certain plant species was identified during the FGDs. *Adansonia digitata* was considered most important for soil improvement. This is because the decaying wood and leaves of this plant produce huge amounts of biomass that are spread on fields as fertilizer. *Ziziphus mauritiana* and *Pterocarpus erinaceus* are additionally considered useful species for wind damage control. On the other hand, *Tamarindus indica* was valued most useful for fire damage control because grass rarely grows underneath this tree, thereby reducing the possibility of fire.

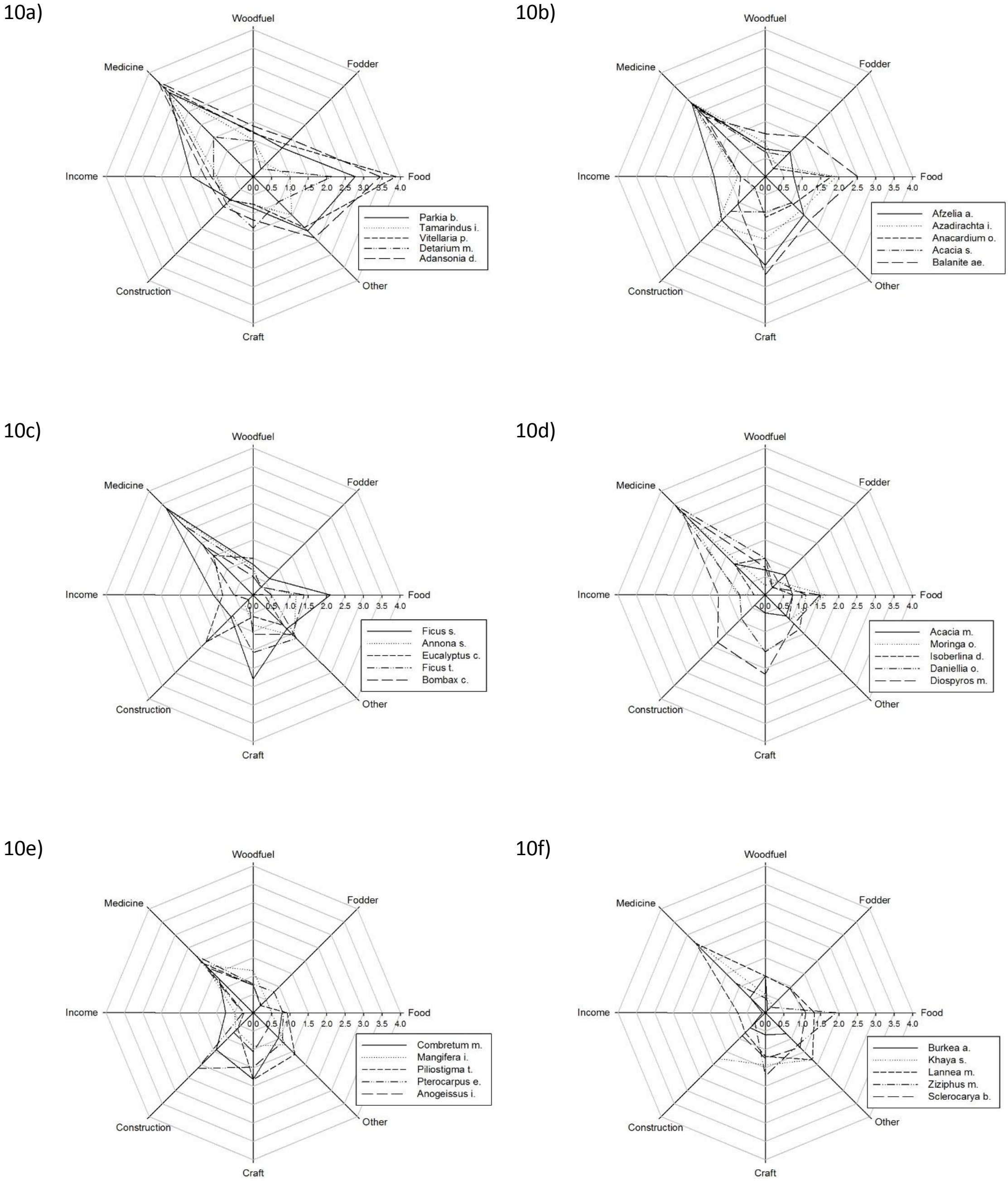

Figure 10. Relative use-values of the 30 selected species across eight use categories

Table 7. Differences in local knowledge (use-value) of all species in terms of gender, ethnicity, age groups, and study villages.

Dependent variable		Freq.	Mean	F [1]	Prob. [1]
Gender as factor 1					
Use-value#	Female	720	0.17086227	60.19	0.0000
	Male	720	0.21145833		
	Total	1440	0.1911603		
Ethnicity as factor 2					
Use-value	Fulani	360	0.19302662	7.37	0.0007
	Gourounsi	540	0.20225694		
	Mossi	540	0.17881944		
	Total	1440	0.1911603		
Age as factor 3					
Use-value#	20–40 years	510	0.14279003	126.92	0.0000
	41–60 years	570	0.20184576		
	61–80 years	360	0.2427662		
	Total	1440	0.1911603		
Study villages as factor 4					
Use-value	Cassou	360	0.16857639	41.08	0.0000
	Dao	540	0.17604167		
	Kou	540	0.22133488		
	Total	1440	0.1911603		

Notes:
[1] One-way ANOVA test of variable "UV" with either equal or unequal variances
Variable violates the Bartlett's test (Homogeneity of variances): assumption of homogeneity of variance is not met.

Table 8. Multiple comparison Scheffe tests for variable "UV" in terms of ethnicity, study villages, and age groups

Dependent variable & factor modalities			Mean Difference (I-J)	Sig.
Use-value &	Male	Female	0.040596	0.000
Use-value & ethnicity	Mossi	Gourounsi	-0.023438	0.001
	Fulani	Gourounsi	-0.00923	0.405
	Fulani	Mossi	0.014207	0.118
Use-value & location	Dao	Cassou	0.007465	0.539
	Kou	Cassou	0.052758	0.000
	Kou	Dao	0.045293	0.000
Use-value & age	41–60 years old	20–40 years old	0.059056	0.000
	61–80 years old	20–40 years old	0.099976	0.000
	61–80 years old	41–60 years old	0.04092	0.000

Multiple comparison Games &Howell test for variable "UV" in terms of age groups and gender

	UV	Diff.	Std.Err	t	adj. P>t
Age	Group 2 vs Group 1	0.0590557	0.0054751	10.79	0.000
	Group 3 vs Group 1	0.0999762	0.0065191	15.34	0.000
	Group 3 vs Group 2	0.0409204	0.0067089	6.1	0.000
Gender	Not applicable (only 2 levels)				

5. Discussion

5.1. Review of the study approach

This study uses an interdisciplinary approach and draws from literature concerning DD and regrowth, revegetation, and afforestation in the light of the forest transition theory. Deforestation is location- and situation-specific and there is no 'silver-bullet' approach for assessing the drivers of DD and revegetation. Though deforestation occurs outside the forestry sector i.e. driven by the agriculture sector and non-forest land uses, other processes influence land-use practices. Understanding the drivers of DD and regrowth requires an approach that cuts across disciplines such as economics, forestry, agriculture, environmental studies, sociology etc. This is because the drivers of deforestation and reforestation are complex and therefore an interdisciplinary approach is invaluable for its understanding. Africa and sub-Saharan Africa (SSA) in particular are complex phytogeographically, politically, socioculturally, economically, and institutionally. Such complexities are an indication that access to resources and control are likely to be different between and even within countries and between different user groups.

This study uses both qualitative and quantitative methods. Data were collected through literature reviews, interviews with key informants, household interviews, FGDs, PPA, a field survey, and participant observations and perceptions. The various methods used during data acquisition forced the researcher to adopt different roles including interviewer, facilitator, and observer. A few questions were not directly posed to the interviewees. For example, to collect data on changes in farm sizes during the ten-year period (2003–2013), farmers were first enquired about their farm sizes in 2003, and then asked to report the area under fallow in 2013. This method reduces the chances of farmers underestimating farm sizes to mask deforestation. As part of the qualitative data, information was collected on farmers' perceptions that were used in combination with quantitative data. Using this perception-based method requires respondents to answer questions according to their recall abilities and understanding of concepts. Apart from understanding the concepts, respondents may strategically depend on the derivable benefits or their understanding of the research purpose (Lund et al. 2011).

The acquisition of data concerning livelihood and environmental dependence may result in random or systematic errors (Angelsen et al. 2011). Systematic errors result from the inadequate understanding of concepts or the over/underestimation of sensitive information such as economic assets, illegal logging etc. Average random error on the other hand does not affect the overall result. A research assistant that has been working on livelihood issues was hired to reduce the error term during the data collection process. The research assistant additionally possesses interpersonal skills such as the ability to communicate in the three local languages used in the communities. The presence of the youth leaders during the interviews efficiently built trust with respondents (Lund et al. 2011). The collection of sensitive data, such as economic assets, farm characteristics (e.g. farm area, fallow, assisted natural regeneration, etc.), were not approached directly. For example, respondents were asked whether all their farm area was cultivated, followed by where they gather fuelwood, fodder, and forest products, and their ownership. Such a set of questions identified farmers with fallow areas. Further questions were asked concerning the estimated size of fallow, its uses, and how much time is needed before its cultivation. A double-check method was used on some sensitive issues such as farm area. This method was easy for farmers not practicing mixed cropping. The interview data was accompanied by an estimation of the cultivated crop area. Such an approach does not mean that the livelihood and environmental dependence data are without errors, but it goes a long way in reducing errors that are likely to occur (Lund et al. 2011).

This dissertation consists of four studies (I–IV). Study I focuses on the drivers of deforestation at the farm/forest level. This study assesses land tenure and asset heterogeneity in relation to deforestation. Land tenure was considered a dichotomy because of the limited user rights granted to migrants. The challenges of using a dichotomy is that land tenure is complex in most cases and differs along a continuum. For example, tenure security might become weaker with an increasing number of fallow years. In addition, changes in farm area during the ten-year period (2003–2013) did not consider fallow areas. The conversion of fallow to agricultural lands induces deforestation (Reenberg et al. 2003).

In the current study, fallow areas were considered as land that will eventually be cultivated and as such should not be considered as deforested. Though tenure security is important in land use decision-making, farm- and household-specific factors should not be ignored. The integration of land tenure alongside asset heterogeneity among farm households is the strength of study I. However, a major weakness of study I is the failure to include household land management practices. The role of sustainable land management practices can improve soil fertility, which may in turn act as a disincentive for field expansion. However, land management practices in relation to environmental degradation form the bases of study II.

Study II uses a PPA method for assessing poverty based on local indicators in the study villages. Such an approach is invaluable for assessing poverty in rural developing countries where assets constitute household wealth (Booysen et al. 2008) and not bank deposits and savings as they do in urban areas and developed countries (Bojö et al. 2001, Bosch et al. 2001). Study II thus uses PPA methods to classify households into different wealth categories based on local indicators. More detailed discussion on the method used in study II may be found in the original article. To understand the local context of poverty in the study area, the key informants were to select participants for the PPA exercise based on the following conditions: (1) having lived in the community for a sufficiently long period to know the level of well-being of other households, and (2) represent as wide a cross-section of the community as possible in characteristics such as gender, ethnicity, status, and neighborhood.

The use of such methods is both case- and context-specific, and should be modified to suit local conditions. For example, two studies in Latin America considered agricultural burning an environmentally degrading activity (Ravnborg 2003, Swinton and Quiroz 2003). On the other hand, in the current study agricultural burning was not seen as a significant environment-degrading activity and was therefore not included. Furthermore, the self-assessments of activities based on farmers' self-reported assessment constituted part of study II. Farmers' self-report of their own land were assessed in relation to overgrazing, tenure security in relation to assisted natural regeneration, and soil fertility loss. Though perceptions may vary among farmers based on their level of understanding of the subject matter, farmers' self-reported assessment was applied to specific issues in the current study. A consensus was found between the indigenous knowledge of farmers and scientifically validated indicators of soil fertility (Karltun et al. 2013).

The focus of study III was on the tree plantations of smallholder farmers. Farmers considered smallholders are supposed to have farm areas of ≥ 2 ha of land and must have planted or currently manage at least one of the following tree species *Adansonia digitata*, *Anacardium occidentale*, *Azadirachta indica*, *Eucalyptus camaldulensis*, *Mangifera indica*, and *Moringa oleifera*. Despite the importance of the selected tree species, which support both livelihoods and revegetation, failure to consider indigenous tree species growing naturally and which could be sustained through assisted natural regeneration constitute a weakness of this paper. Including indigenous tree species, such as *Parkia biglobosa* and *Vitellaria paradoxa*, would have been more informative. However, these species are protected by law and farmers are likely to avoid providing information on the true status of such species located on their farms. However, a study in Burkina Faso found that parkland systems suffer from degradation due to forestland conversion to croplands. The natural regeneration of indigenous tree species is thus invaluable for reversing such trends. The ongoing regreening process in the Sahel has acknowledged the role of assisted natural regeneration in improving regrowth (Sendzimir et al. 2011). The strength of study III is that it considers both current and previously planted trees that have not been harvested by farmers. This is because certain farmers might not have planted trees in the last three years but did so years ago.

Study IV describes the use-values of trees in relation to local knowledge with a focus on livelihood values and their potentials for environmental protection. Information from this study is based on botanical knowledge of thirty commonly exploited tree species based on a previous study conducted in the region (Paré et al. 2008) in combination with interview results from key informants. The challenge of using only a few species is that important plant species used by certain groups may be excluded. Considering the botanical knowledge of existing plant species in the study villages may unmask the hidden knowledge that is likely not captured when few species are considered. For example, cattle herders (Fulani) are more knowledgeable of plant species due to their daily interaction with the environment (Ayantunde et al. 2009). Activities or professions therefore influence the accumulation of local plant knowledge as women have been found to have more knowledge than men on plant species used as condiments and food (Ayantunde et al. 2008). The limitation of study IV to 30 mostly-woody species may be one reason for men having more knowledge than women on the plant species in our study.

5.1.1. Limitations of the forest transition theory

The forest transition theory is invaluable for understanding forest cover dynamics and the likely position of nations along the transition curve (Mather 1992). This theory has been applied by different disciplines to better understand the mechanisms that drive DD and regrowth/revegetation. The forest transition theory therefore represents a convenient approach for explaining forest cover dynamics, an important information for both climate change adaptation and mitigation. This theory is based on two chains of reasoning: the economic development path (such as in developed countries) and the forest scarcity path (the case of China and other developing countries) as drivers of revegetation after a period of deforestation. The forest transition theory hypothesizes that deforested areas will eventually begin to reforest, makes it more of a straightforward relationship. Based on the forces in operation, deforestation can lead to more deforestation, while reforestation in developing countries may be driven by other factors apart from forest scarcity creating incentives for tree planting. The importance of this theory in relation to land cover dynamics should therefore not ignore the limitations associated with it. Such a limitation does not make the theory less important, but we must be conscious in its application.

The forest transition theory mainly investigates two trajectories; the economic development and forest scarcity paths, but it can also be affected by sociocultural, economic, and biophysical conditions that are likely to deliver case- or situation-specific outcomes. Forest transition in developing countries is generally expected to be driven by forest scarcity while economic development drives the transition in developed countries. This may not be realistic because awareness of forest scarcity without the implementation of governmental reforestation policies or an enabling environment for tree planting and conservation activities may not result in a transition (Rudel et al. 2005).

The theory does not consider different forest types, which are likely to affect forest outcomes (Robinson et al. 2013). Changes in forest cover are usually measured as percent of land area, but this does not provide an accurate measure of actual forest quantity. A critical review, indicates certain weaknesses of the forest transition theory According to Perz (2007), forest transition is based on experiences gained in industrial countries and historical context-specific explanations of forest transition dynamics have been ignored. Different forest dynamics patterns than those expected in forest transition have raised criticism against the theory. For example, deforestation and reforestation are ongoing activities in sub-Saharan Africa, and the Sahel in particular. Biophysical factors (seasonal rainfall and soil fertility), social and economic inequality, land and tree tenure security, and political factors are therefore essential when analyzing forest transition dynamics in developing countries.

Furthermore, little attention has been devoted to the conditions where a transition may likely not occur. As such, details are important for understanding different factors that may influence or deter forest transition. Variables influencing deforestation rates, the amount of primary forest remaining at the point of transition, the rate and extent of recovery, and how these factors influence each other are not well defined, though very crucial to understanding forest transition. The issue of spatial scale should also be addressed, as it investigates the spatial distribution of forest cover reduction and recovery at a given moment in time over larger land areas. Greater attention is needed when dealing with multiple temporal scales to avoid overlooking forest dynamics in the short- and medium-terms. These short- and medium-term forest dynamics may introduce changes that can distort the forest transition theory from a smooth, incremental transition curve.

Another form of criticism is the lack of consensus concerning the explanatory mechanisms of the transition, which have been approached differently. No universal explanatory variable exists, and some are included without specific theoretical foundation. These explanations have operated at different scales in the form of important factors behind forest dynamics in both developed and developing countries. How general these explanatory variables are in obtaining the theoretical perspective of forest transition between developed and developing countries have been questioned (Perz 2007). The mechanisms are not similar between both nations. Therefore, not only is the variation in a causal factor essential, but different causal factors may also be important for explaining forest change in different contexts.

However, some suggestions have been made to improve the effectiveness of using this theory. Forest type must be clarified i.e. primary or secondary, the study approach should be interdisciplinary, and should recognize the short- and medium-term dynamics without losing focus on long-term transitions. The drivers of forest transition at different scales should be acknowledged (Perz 2007). Based on these suggestions for improvement, the current study indicates that forest type is secondary, while the focus is on the farm/forest level, cutting across disciplines such as forestry, economics, botany, agriculture, environmental studies etc.

5.2. Drivers of deforestation and forest degradation

Forests provide a number of valuable goods and services to society. However, the high returns generated from non-forest land uses sets the protection of forest ecosystems at a disadvantage and act as incentives for deforestation (Kanninen et al. 2007). The situation is challenging particularly in the Sahel and Burkina Faso given their phyto-geographical setting that exposes the central and northern region to the impacts of drought and desertification. Better conditions for rain-fed agriculture have attracted migrants (Mossi and Fulani ethnic groups) to the southern region during the last three decades. Given that over 70% of the country's forests are located in the southern region, the pressure has increased on natural resources such as croplands, fuelwood, fodder, forest products, water resources etc. Local institutions and household socioeconomic factors are therefore re-enforced by national policies of land resources that eventually influence deforestation.

The annual deforestation rate for Burkina Faso ranges from 0.91% to 1.03% (Fischer et al. 2011), while it is 0.96% per annum in the southern region (Ouedraogo et al. 2010). Some studies in Burkina Faso have assessed deforestation in relation to land-cover change (Paré et al. 2008, Ouedraogo et al. 2010, 2015). Though such an approach is crucial, it does not provide information on the forces that drive land-use decision-making at the farm level. Thus, understanding the drivers of deforestation at the farm level (study I) is crucial to identifying appropriate incentives to curb deforestation.

Agricultural activities have been found as the dominant non-forest land uses driving deforestation in the tropics (Hosonamu et al. 2012), sub-Saharan Africa (Angonese and Grau 2014), the Sahel, and Burkina Faso (Ouedraogo et al. 2015). Over 70% of the population in Burkina Faso is rural and depends on agropastoral systems as their main source for income and livelihood (FIP 2012). Natural increases and migration of farm households to the southern region have increase demand for arable land. This increase in the rural population in the receiving region has resulted in land scarcity and the shortening, and in certain cases disappearance, of fallow areas.

Land management practices considered as sustainable e.g. improved fallow etc. are important for soil fertility management especially in Africa, whose input in agriculture has not improved for decades. Increasing farm production per hectare under situations of low input require an increase in the area under cultivation (DFID 2004). This results in field expansion into community forest areas; an important process that drives deforestation in Southern Burkina Faso. The lack of adequate monitoring over common pool resources have acted as an incentive for field expansion by certain farmers when faced with low farm production.

The complexity of the drivers of deforestation makes them location- and situation-specific because a factor affecting forest cover in a region may not do so in another. The role of tenure is another factor that has been applied to studies on deforestation. A meta-analysis in the tropics found that tenure security improves forest cover (Robinson et al. 2013). On the other hand, clearing forest improves tenure security in certain cases, while varying along a continuum in others. For example, tenure insecurity might increase as fallow areas grow much older. Farm households who perceive their tenure to be insecure are likely not to adopt old-growth fallows.

In rural Burkina Faso land is administered by the land chiefs and governed by customary rules (Ouédraogo 2002). Land tenure varies between the indigenous and migrant groups (Fulani and Mossi) as follows; (i) rights of permanent use, granted to the indigenous group (autochthons), (ii) rights of permanent use, acquired by claiming unclaimed forested land (open woodlands without protection), (iii) rights of limited use, extended to indigenous groups who need to borrow land. Depending on the group, the above-mentioned rights may become rights of permanent use if held for more than one generation, (iv) rights of limited use, granted to 'strangers' (non-indigenous people) who borrowi the land (Ouédraogo 2006). These latter rights can become permanent after generations of being passed down, particularly if the borrower has improved the land (Gray 2002). Tenure security is an incentive for investment, a finding similar to an earlier study in Burkina Faso (Brasselle et al. 2002). Another study found that rural migration is a threat to environmental sustainability in southern Burkina Faso, as migrants were using ox mechanization to convert forest to croplands (Ouedraogo et al. 2009).

Cotton cultivation is among the drivers of deforestation in Burkina Faso (Kambire et al. 2015). According to Ton (2001), the expansion of cotton production in West Africa is driven by households equipped with animal traction, while those with manual tools have been unable to participate effectively in this source of income. With such findings, the farm area under cotton cultivation may be influenced by the availability of agricultural equipment. Aside from cotton cultivation, land grabbing by some influential elites for agribusiness development in the last decade have induced deforestation. Understanding the drivers of deforestation should therefore incorporate household assets, and socio-cultural and institutional factors governing access to land that are invaluable in land-use decision-making (Study I).

Furthermore, wood energy (fuelwood and charcoal) still remains the main source of household energy that is harvested from community forests. The community forest areas in the southwestern region were created for the purpose of supplying fuelwood to the rural and urban population of the country. Increase in demand has led to overharvesting and illegal logging, thereby leading to forest degradation. The occurrence of trees in the parkland systems have not solved the wood energy crisis, rather, these systems are rapidly degrading (Bayala et al. 2011, Belem et al. 2011) due to over harvesting and other activities considered environmentally degrading. As such, household economic asset was used to assess the wealth categories responsible for environmental degradation (study II).

5.3. Poverty and environmental degradation

Land degradation is another problem confronting smallholder farmers in sub-Saharan Africa. The provisional goods and services derived from tropical landscapes have been degraded partly through inadequate land management practices. A recent study found that African soils are the most degraded (Le et al. 2014). Evidence of land degradation in sub-Saharan Africa and the Sahel are reflected in lower crop and livestock productivity and production, with potential negative social and economic implications (Mirzabaev et al. 2015). These impacts include a growing population with increasing demands for food, fuel, fiber, and fodder with little or no input into agricultural practices and little opportunities for off-farm employment. The main form of access to land in Burkina Faso is through the inheritance system for the indigenous groups. Farm ages of eighty years were identified in the study area and sustainable land management (SLM) practices in combination with inputs, such as fertilizers, is needed to maintain or even improve farm production under such conditions. However, agricultural productivity is very low in Africa and has not improved for decades (DFID 2004). Given the low adoption rate of SLM practices among farmers in the tropics (Nkonya et al. 2014) further justifies why the soils of sub-Saharan Africa are the most degraded compared to other developing countries (Pender et al. 2009).

Identifying the drivers of land degradation at the household level may therefore be fairly challenging because they cut across farmer-specific, farm-specific, and institutional factors affecting farmers in various ways. Empirical studies on the drivers of land degradation have focused on the questions of whether population increase causes land degradation (Grepperud 1997, Vu et al. 2014) or leads to SLM (Tiffen et al. 1994); whether poverty is the cause of environmental degradation (Bojö et al. 2001, Bosch et al. 2001, or not (Nkonya et al. 2008); does higher market access lead to SLM (Nkonya and Anderson 2014) or to land degradation (Scherr and Hazell 1994). These questions are important as they influence various household socioeconomic and institutional factors that eventually cause degradation (Le et al. 2014). Therefore, the resources available to households, their tenure security to land and tree resources, and what land management practices they adopt can provide a better understanding of land degradation.

For example, improving cropland in Burkina Faso is considered a sense of ownership, and given the rights of limited use accorded to migrant farmers, is likely to affect their implementation of SLM practices. Assisted natural regeneration of indigenous tree species is a low-cost and labor-efficient way of improving land in the Sahel. Other practices considered environmentally degrading include cotton cultivation, overharvesting of fuelwood, deforestation, overgrazing, and the lack of SLM practices such as fallow, planting pits, life hedges etc. Understanding the natural resource management activities of different wealth categories and their perceived activities that are likely to cause environmental degradation is therefore important for prescribing policy measures for mitigating these problems (study II).

5.4. Smallholder tree plantations and assisted natural regeneration activity

Tree planting activity by smallholders was influenced by economic motivation including income generated through the sales of wood, fruit, and other tree products, the market for certain tree species, and support from projects either through free seedlings or at reduced prices. Tree planters and non-tree planters thus differ in their socioeconomic characteristics as reported by previous studies (Simmons et al. 2002, Emtage and Suh 2004, Kallio et al. 2011). In general, tree planters were smallholders with large land areas and having belonged to farmers' groups for more years, aiming to manage forests. In addition, they were farmers with more resources who can afford to wait for trees to attain harvesting age before receiving income from wood and tree resources, and also had a more favorable attitude towards tree planting (study III).

Tree plantations are important for the reforestation of degraded lands or to improve on-farm tree cover. Burkina Faso fits into the forest scarcity pathway of the forest transition theory given that the central and northern regions are affected by drought and desertification. The Sahelian droughts of the 1970s created an opportunity for reforestation and afforestation programs because of the importance of trees for livelihood values and its mitigation potentials to the impacts of climate change (Bayala et al. 2014). These programs were designed to fit local conditions such as the regeneration of indigenous trees and the development of monoculture industrial plantations.

Smallholder tree planting activity in the current study was based on the following six species: *Adansonia digitata*, *Anacardium occidentale*, *Eucalyptus camaldulensis*, *Moringa oleifera*, *Azadirachta indica*, *and Mangifera indica*. Across the four study villages, the highest number of planted or currently managed trees was found in Cassou. Five of the six species dominated in Cassou with the exception of *Mangifera indica*. Information from key informants reveals that Cassou's long history of development projects owing to its administrative role as the district head of the Ziro province explains why it has larger benefits than other villages. For example, there is an ongoing project supported by "Centre National de Semences Forestieres" (CNSF) through a farmers' group called Cayendé consisting of thirteen members. This project (2010–2016) supports a tree nursery of *Adansonia digitata* and *Moringa oleifera*. Given that the nursery is located in Cassou, smallholders must travel from Vrassan, Dao, and Kou, which are 15, 35, and 40 km away to buy seedlings. Easy access to planting materials therefore contributed towards tree planting, a finding that corroborates a previous study in Indonesia (Kallio et al. 2011).

Irrespective of different factors and characteristics influencing tree planting, the ongoing regreening process in the Sahel acknowledges the importance of tree plantations and the FMNR of indigenous tree species (Sendzimir et al. 2011) for regrowth/revegetation. For example, the Maradi and Zinder Regions of Niger have experienced a dramatic reversal on once-degraded lands in the last two decades. Two million trees are estimated to have regreened an area of five million hectares that currently secure the livelihoods of approximately 4.5 million people (Reij 2006, WRI 2008). Despite the increase in rainfall in the Sahel during the last three decades, the ongoing regreening process would not have been possible without human interventions (Olsson et al. 2005, Herrmann et al. 2005, Seaquist et al. 2008). Forest transition in Burkina Faso is driven by a combination of tree plantations (monocultures), soil and water conservation techniques e.g. planting pits and the regeneration of indigenous tree species that are typical to the Sahelian landscapes. Tree plantations in Burkina Faso receive support from various actors and during a 2005 reforestation campaign, apprximately 93% of the seedlings planted came from private nurseries, while 7% came from government agencies (MECV 2006).

Aside from providing seedlings, farmers have been trained on the grafting technique by TREE AID to generate planting materials for the mango. Specific factors thus affect the planting of different tree species. Planters of *Eucalyptus camaldulensis* had larger farm areas because it is considered the worst in terms of damaging the soil. During the FGDs, participants mentioned that although this species provides multiple products and has access to local markets, managing it on small farms together with crops is challenging. Planters of *Anacardium occidentale* mentioned that the planting of this species is the outcome of the spill-over effect from the African Cashew Initiative (ACI), which was implemented in neighboring Sissili province. Forest transition is therefore driven by a combination of factors operating at various levels and driven by household and institutional factors that differ among farmers.

5.5. Tree knowledge for livelihood values and environmental protection

Trees constitute an important component of the agricultural landscape in the Sahel. These systems reflect the ecological knowledge of farmers in a risk-prone environment where trees play an important role in livelihood and environmental protection (Bayala et al. 2014). Parkland trees provide multiple goods and services, such as food, fuel, fiber, fodder, provide infiltration channels thereby reducing soil erosion, improve soil fertility through the decomposition of biomass, and buffer the impacts of climate change. The multiple uses of these tree species is connected to botanical knowledge that varies across age groups, ethnic groups, location, and between genders. Ethnobotanical knowledge on selected tree species was assessed in relation to livelihoods and environmental protection using the use-value method (study IV).

According to IUCN classification *Afzelia africana*, *Khaya senegalensis,* and *Vitellaria paradoxa* are considered vulnerable in this study and considered a priority for conservation. The most valued tree species in the selected categories are as follows: food (*Vitellaria paradoxa, Adansonia digitata,* and *Parkia biglobosa*), fodder (*Balanites aegyptiaca, Adansonia digitata,* and *Vitellaria paradoxa*), woodfuel (*Adansonia digitata, Parkia biglobosa,* and *Vitellaria paradoxa*), medicine (*Adansonia digitata, Vitellaria paradoxa,* and *Daniellia oliveri*), income (*Parkia biglobosa, Afzelia africana,* and *Adansonia digitata*), construction (*Pterocarpus erinaceus, Azadirachta indica,* and *Diospyros mespiliformis*), craft (*Balanites aegyptiaca, Afzelia africana,* and *Ficus sycomorus*). In general, botanical knowledge differed significantly among men, with the elderly age group having much more local knowledge on selected plant species.

Plant species showed differences in their uses in relation to environmental protection. For soil improvement, *Adansonia digitata* had higher use-values followed by *Parkia biglobosa*, *Vitellaria paradoxa,* and *Piliostigma thonningii*. The decaying wood and leaves of *Adansonia digitata* produce huge amounts of biomass, which is spread on fields as fertilizer. Trees in this use category produce biomass from fruits, tree bark, and leaves falling that improves soil fertility. Aside from soil improvement, botanical knowledge on tree species has been used to reduce uncontrolled bush fires and to act as wind damage protection. On the other hand, *Ficus thonningii*, *Bombax costatum*, *Afzelia africana,* and *Azadirachta indica* that thrive easily on poor soils have been used in the rehabilitation of degraded lands. Botanical knowledge of plant species can thus provide both livelihood values and environmental protection.

6. Conclusions and Recommendations

The current study focuses on the drivers of DD and activities that support regrowth/revegetation in the light of the forest transition theory. The need to understand the drivers of DD is important for aiding the implementation of policy measures to curb deforestation. The recurrence of the Sahelian drought since the 1960s has marked this region as a society unable to cope with the uncertainties emanating from natural variability and socioeconomic change. Located south of the Sahara desert, the central and northern region of Burkina Faso suffers from drought and desertification. This has led to crop failure that eventually causes periodic famine and poverty. Farmers have adopted various strategies for coping with these uncertainties, e.g. migration to the southwestern region that offers better opportunities for rain-fed agriculture. In search of better livelihood opportunities, migration to the southern region has increased in the last three decades. Population changes in the receiving region have introduced changes in land use and land management practices.

Over 70% of the forests in Burkina Faso are found in the southwestern region inclusive of national parks that are under strict protection. The rainfall in this region is the highest in the country, which supports not just farming but provides year-round fodder supply, wood energy, forest products, etc. Managed forests in the country are found in this region and land access is governed by customary rules administered by land chiefs. One of the studies assesses the role of tenure and asset heterogeneity on deforestation (study I). In this study, tenure insecurity and low agricultural production expressed in the sizes and ages of farms lead to an increase in deforestation. From literature, the drivers of deforestation are case-specific and assessing them at the farm/forest level is important to enable the formulation of adequate policies.

The rights of limited use of the land accorded to the migrants made them borrowers of the land, especially with the lack of monetization of the land. Migration status is a proxy for tenure insecurity, with farmers drawing much resources from the land. Greater rights and an improved legal status may reduce the limited usage rights granted to migrants. This may create a sense of ownership, thereby acting as an incentive for investing rather than just drawing from the land. Aside from tenure insecurity, farmers take advantage of the poor monitoring of community forest areas to expand their fields. There are existing laws in Burkina Faso to issue a fine to farmers encroaching into managed forest areas, but the lack of enforcement has created an enabling environment for violation.

On the other hand, the inheritance system is common among the indigenous groups (Gourounsi) and is being adopted even by the migrants that dwell permanently and have become part of these communities. In this system, land is shared among the male children, which has a long-term impact. Farm ages of up to 80 years were identified in the present study, with a reduction in farm area as land is shared among the adult males. The input into agriculture is very low and productivity reduces with increase in farm age. Faced with such a situation of periodic hunger, field expansion into managed forests with fertile soils has become an intensification strategy thereby driving DD and the loss of ecosystem goods and services. Furthermore, agricultural intensification in Burkina Faso portrays a different meaning. Diversification and the use of farm input, such as fertilizers and the adoption of SLM practices, are expected to be widely adopted among farmers to intensify land use. The adoption of SLM is affected by household socioeconomic and institutional factors.

Study II uses a PPA method to understand the relation between poverty and environmental degradation. This study is important because SLM practices in the Sahel e.g. planting pits, stone bunds etc. are considered to be labor-intensive, implying that household socioeconomic conditions are invaluable for their adoption. Deforestation is among the activities of environmental degradation in study II and its rate was highest for the non-poor farmers. In addition, the non-poor and fairly poor farmers participated most in activities identified as environmentally degrading such as overgrazing, cotton cultivation and the cutting and selling of fuelwood. On the other hand, the adoption of sustainable land management practices was relatively low among the poorest farmers. Therefore, the results of our study indicated that the non-poor and fairly poor farmers contributed toward environmentally degrading activities while poverty constrain the adoption of land management practices considered to be sustainable.

In this study was found that the drivers of DD are very complex but interrelated because land use decision-making at the household level cuts across sociocultural, economic, institutional etc. factors. Though tenure insecurity was important in explaining deforestation, other factors should not be ignored. Fallow land played an important role in reducing deforestation among farmers from the indigenous groups. Improved fallows should be promoted by agricultural extension services in the area by providing farmers with nitrogen-fixing tree species. This method is low in cost and has been proven to be significant in soil fertility management. The increase in the migrant population alongside the cattle herders has not only increased the number of cattle but also their stocking density. To solve the problem of overgrazing, existing grazing lands should be improved by planting important fodder trees such as *Pterocarpus erinaceus*, *Afzelia africana,* and *Balanites aegyptiaca*. Priority should be given to degraded grazing lands for enrichment planting while controlled grazing should be implement by organizing cattle herders into farmers' groups.

Evidence found in this study show that tree planters were smallholders with larger land areas, having belonged to farmers' groups for more years, aiming to manage forests. In addition, the main reasons for planting trees were economic motivation including income generated through the sales of wood, fruit, and other tree products, a market for certain tree species, and support from projects either through free seedlings or at reduced prices. Tree planters and non-tree planters thus differ in their socioeconomic characteristics. Notwithstanding such differences, tree planting is one of the measures promoted by development programs to increase the adaptive capacities of vulnerable communities to the impacts of climate change. It is believed that tree planting will positively contribute to livelihoods by buffering the effects of climate change while creating opportunities for diversification. Furthermore, assisted natural regeneration of indigenous tree species was found to influence the regrowth of trees on farms. This practice is important because the Sahelian landscape is a combination of trees, crops, and livestock that have been developed by farmers for generations to reduce their vulnerability to risks related to climate variability.

Parkland systems generally incorporate indigenous trees species that constitute important sources of food, fodder, fuel, fiber, medicine etc. These systems reflect the ecological knowledge of the farmers, which is utilized based on local knowledge transferred from one generation to another. Some of these species grow on poor soils and have been used in the rehabilitation of degraded lands. As indicated in the study, intervention from the government and (NGOs) has promoted the planting of different tree species in the last fifteen years. Currently, there are ongoing tree planting projects in Cassou for *Adansonia digitata* and *Moringa oleifera*. Some of the challenges associated with the development of tree plantations and assisted natural regeneration of indigenous tree species include a preference to agriculture due to the shorter waiting time, low prices for wood and tree resources, difficulties accessing markets, land and tree tenure issues etc.

Is forest transition likely to occur in Burkina Faso, whose central and northern regions suffer from the impacts of drought and desertification? Evidence from a previous study indicated that non-forest land uses in southern Burkina Faso caused the loss of 50% of its original forest cover. This implies the region has experienced stage two of the forest transition curve. The high rates of deforestation in the southern region can be linked to the following: (i) approximately 70% of the country's forests are found in the southwestern region, (ii) this region offers better opportunities for rain-fed agriculture, which support the livelihood of 70% of the country's population, (iii) low input into agriculture has acted as an incentive for field expansion to augment farm production etc.

In stage three of the forest transition curve, indigenous trees together with crops constitute an important land-use system in the Sahel known as parkland systems. These systems of trees and crops on farms creates a mosaic landscape similar to stage three of the forest transition curve. However, the maintenance and sustainability of these systems depends on its original cover, the needs of farmers, type of land management practices implemented, and land and tree tenure security issues. However, tree planting and assisted natural regeneration of indigenous trees are important drivers of regrowth/revegetation in this region. Ongoing activities present a more complex picture in which DD and regrowth/revegetation activities occur simultaneously. The role of remote sensing using time series is invaluable for assessing dynamics of forest cover over various periods in time.

Despite the potential of tree planting for improving forest cover, their success rate is very important because some seedlings die shortly after planting. Assessing the success rate of trees planted is another area for further research. The monetization of land is expected to bring agribusiness investors into these community. Such a shift may weaken the customary land tenure system as the so-called 'new stakeholders' will be granted legal claims to the land as opposed to legitimate claims. Another study on agribusiness development and its impact on local livelihood would invaluable. Finally, trees and forest-based livelihood diversification strategies to increase the adaptive capacities of local communities should be considered for further research.

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Annex

Household questionnaires

Date of interview………………………..

Name of village………………………….

Section A: Description of household

1. Name of household head/Respondent………………………………………………..........
2. Age of household head……………………………………………………………………..
3. Marital status; Single……..Married……..…Divorced…..…..Widow…..…Widower……….
4. Household size…………………………………………………………………………………..
   Number of adult males……………………….adults female………………………………….
   Children (males)………………………………Children (females)……………………………
5. Ethnic group; Gourounsi…………………..…..Mossi………………….Fulani…………………
6. Years of living in village……………………………………………………………..
7. Education
   (i) Number of years in school…………………………………………………………
   (ii) Cannot read or write; Yes…………………No………………
   (iii) Can read or write; Yes……………………..No……………….
   (iv) Can read and write; Yes…………………..No………………...

Section B: Land and tree tenure issues

8. Do you cultivate in different fields; Yes……………………No…………………………….
9. If yes to question 8, how many fields………………………………………………………
10. What is the size (ha) of each field………………………………………………………..
11. How was the land acquired
    (i) Inheritance………………………………………………………………………
    …….
    (ii) From the community in exchange of gift……………………………………………..

(iii) Others, please specify……………………………………………………………………

12. Do you practice sharecropping?
Yes………………………No………………………………
13. If yes to question 12, is it your main source of access to land?
Yes…………..No…………...
14. For how long have you cultivated this field?..
15. What was the land use/land cover before you began cultivation?
Forest……..…….Fallow…………..Farmland……………Other, please specify………………….
16. What is the distance (km) from you field(s) to the forest? Field 1…..Field 2……Field 3……
17. Do you require permission to plant certain crops in the field?
Yes……..…No……………..
18. Do you require permission to plant trees in the field you cultivate?
Yes…………No……….
19. Who harvest the trees in your field if any? Household members............Other, please specify………………………………………………………………………………………..
20. Do you have trees in your field(s) that have regenerated?
Yes…………..No………………..
21. If yes, how old are they?……………………....If no, why?..

<u>Section C: Crop production system</u>

22. Which of the following do you cultivate?
Sorghum………..Sesame………….Millet……….
Cotton………Groundnut………..Beans…….Rice……..Other, please specify…………………….
23. What is the estimated quantity (kg) produced in 2013?
Sorghum………Sesame…….Millet…….Cotton…….Groundnut…….Beans……Rice …….
24. Estimated quantity of crop sold in 2013; Sorghum……….Sesame………..Millet…….. Cotton………Groundnut………..Beans……..Rice……..
25. Cultivated area of crops (ha) in 2013; Sorghum……….Sesame…………Millet……… Cotton……..Groundnut……….Beans………Rice……….

<u>Section D: Livestock and production system</u>

26. Do you own cattle, goat, sheep or donkeys? Yes……….No………….
27. Indicate type of livestock and their number in 2013.
Cattle…..……Donkey……………
Sheep…………Goat…………Other, please specify………………..
28. Has the number of livestock increased or decreased compared to the last five years?

Increased………Decreased………… and why?..

29. Where do you collect fodder for your livestock?
Fields……………..….Fallow……………..
Forest…………………Other, please specify…………………………
30. What is your perception on the available quantity of fodder for your livestock?
Sufficient…………..Not sufficient…………….and why………………………………
31. Are additional sources of fodder needed aside from that of the rangeland, crop residues, and fallow? Yes…………No……………Give reason for answer……………………………
32. What is your assessment concerning the quantity of additional fodder sources needed by your livestock?
Low………………Moderate………..………High…………………..
33. Which of the following trees have you planted/currently managing on your farms?
Adansonia digitata………………….*Anacardium occidentale*……….…………
Azadirachta indica………………....*Eucalyptus camaldulensis*…………………...*Mangifera indica*………… *Moringa oleifera*………………..
34. Please estimate the number of trees you planted/currently manage on your farm(s)
Adansonia digitata………………….*Anacardium occidentale*……….…………
Azadirachta indica………………....*Eucalyptus camaldulensis*…………………...*Mangifera indica*………… *Moringa oleifera*………………..
35. List the tree species you prefer that are not available to you?...
……………………………………………………………………………………………..
36. Could you mention what motivated you to plant any of the selected species? Multiple reasons are allowed for each species: Economic…………….Building material…………….Fuel wood……………Incentives……………….Access to markets…………Support for tree planting…………………Environmental……………Land security………………Low labor requirements………………………………..
37. What are your reasons for not planting any of the selected species? Land is not sufficient…..
Lack of seedlings/higher prices for seedlings……….…...Prefer agriculture to tree planting………Not profitable (low prices)……………Lack of markets…………….Longer rotation period………………Health problems……….No time/labor……………Unsuitable land…………Lack management knowledge of trees……………………………Newcomer in the village……………..Lack tenure security to land and trees……………………………
38. Indicate previous or planned use of income derived from each of the species in the following categories: daily consumption (1), anticipated expenditures (2), and unexpected expenditures (3). *Adansonia digitata*

(1)………(2)………(3)……..*Anacardium occidentale*
(1)………(2)..………(3)…….. *Azadirachta indica*
(1)………(2)………(3)…......*Eucalyptus camaldulensis*
(1)………(2)………(3)…...*Mangifera indica* (1)………(2)…..…(3)………. *Moringa oleifera* (1)………(2)………..(3)…………..

39. Do you belong to a farmers' group? Yes……………No……………….
40. Are you a member of the forest management group (FMG)? Yes..................No....................
41. Willingness to plant each of the six species? Yes……………No……………..and why……………………………………………………………………………………………….

Section E: Household energy system

42. Type of household energy. Wood……………kerosene…………..gas……………
Crop residue……………charcoal……………..other…………………..
43. Source of wood energy. Forest………………farm……………..fallow land………
Other farms…………….purchasing………………………..
44. Has the distance from the energy source changed in the last five years? (0) No………
(1) Yes…….
45. If yes to question 44, give reasons……………………………………………
(1) Lack of trees on farm……………………………………….
(2) High demand for wood leading to deforestation……………
(3) Population growth………………………………………….
(4) Other, please specify………………………………………………
46. Who collects fuel wood? Male……………Female…………..Both…………….
47. Estimated quantity (in chart) collected per month……………………………..
48. Estimate fuelwood consumption of your household per month…………………
49. Quantity of fuelwood sold……………………………………………………….

Section F: Land and forest management system

50. Could you estimate the size of your field(s) in 2003?...
51. How much of the land (ha) was cultivated in 2003?...............under fallow…………
52. What is the size of your field(s) in 2013?..
53. How much land is currently cultivated?...........................Under fallow……………..
54. What is your assessment on the level of top soil loss in your field(s)?
Low……………...
Moderate……………………………High……………………………………………
55. What activities do you consider to cause land degradation?…………………………………..
………………………………………………………………………………………..
56. Which of the following land management practices have you adopted?
Fallow…………
Planting pits………Use of compost………..Stone bunds…………Life hedges…………

57. Give reasons to support answer in question 56…………………………………………...
58. Can you identify this plant species?
    Yes……………………No……………………
59. Indicate with a tick the importance of this species from the list below
    (0) A species of low quality…………………………………….
    (1) Good, but only used occasionally………………………………….
    (2) Useful species……………………………………………….
    (3) Preferred species…………………………………………….
60. In what ways can this species be used in the following categories? List all the uses you know in each category.
    Medicine. What ailments can it cure?1……….2……….3……….4……..5……..,etc…
    Fodder. In what ways can it be used as fodder? 1………..2……….3……..4………….
    Food. In what ways can it be used for food? 1……….2………3………4…………..
    Wood fuel. 1……….2……….3…………4………….5…………..6…………………
    Income.
    1……………2…………3…………4……………..5………………6…………
    Construction.
    1…………..2……………3…………….4………………..5……………..
    Craft.
    1…………..2……………3…………….4………………5…………..6………….
    Others (Environmental protection and spiritual values).
    1………2……..3……….4…….