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Finally, I could not have completed this without the unfailing love and support of my family and friends. Thank you.
To the farmers

finally may your voices be heard

And in memory of Sean McCabe

for encouraging me to believe in my dreams
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Chapter One: Introduction

This study explores whether and, if so, how agroforestry techniques can help subsistence farmers reduce their vulnerability to climate change. Climate models predict that climate change will cause, among other things, decreasing rainfall in arid areas, warmer temperatures, and increasing severity and frequency of extreme weather events [1]. It will be necessary to help small-scale farmers adapt to these significant climatic changes. Agroforestry, or the intentional use of trees in the cropping system, has been proposed by many development practitioners as a potential strategy to help farmers reduce their vulnerability to climate change.

From field research conducted in western Kenya, I investigate how recent climate-related shocks and stresses have affected subsistence-farming communities. I find that farmers are not coping with floods, droughts and rainfall variability in a sustainable way. To cope with extreme weather events and variations, farmers are forced to sell farm tools, consume seeds reserved for planting and engage in other strategies that further drive them into poverty. Farmers believe that the most effective way to improve their capacity to adapt to climate-related shocks is through improving their general standard of living. I then examine how agroforestry techniques help farmers reduce their vulnerability to these climate-related shocks. By comparing farmers engaged in an agroforestry project with a control group of neighboring farmers. I find that agroforestry does help farmers reduce their vulnerability to climate related-hazards. Engagement in agroforestry improves household’s farm productivity, off-farm incomes, wealth and the environmental conditions of their farm. I conclude that agroforestry techniques should be used as a part of future adaptation programs to help subsistence-farmers reduce their vulnerability to climate-related hazards. I end with recommendations on how to improve the efficacy of such programs.

Background

Over two billion people live on less than two dollars a day and 75% of these poor people can be found living in rural areas [2]. Three quarters of rural dwellers in developing countries are tied directly to agriculture and ecosystem services. Climate change is expected to decrease agricultural productivity in the developing world by 10-20% over the next forty years [3]. With so many of the rural poor reliant on agriculture for a way of life, these changes will have significant impacts for the rural poor [4]. Climate models predict that climate change will cause, among other
things, decreasing rainfall in arid areas, warmer temperatures, and increasing severity and frequency of extreme weather events [5].

Subsistence farmers in the developing world are particularly unable to cope with such climate variability, as they do not have the capital to invest in new adaptive practices with which to protect their homes and families. They are also especially sensitive to climatic changes as they rely almost entirely on rain-fed agriculture for their way of life. There has been a recent focus in the international development community and literature on strategies to help subsistence farmers reduce their vulnerability to climate change in developing countries [6].

Framework

According to the Intergovernmental Panel on Climate Change (IPCC), climate change vulnerability is “the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes” [7]. In this paper, I use Turner et al.’s (2003) vulnerability framework that assesses how marginalized people are affected by outside shocks and stresses [8].\(^1\) Turner et al. divide a system’s vulnerability into three major components, see Figure 1.1 for a visual representation. First, there is the exposure of a system to hazards, which considers the frequency, magnitude and duration of this exposure. Hazards include any threats to the system, both sudden shocks (like floods and droughts) and slow increases in stress on the system (due to soil degradation, increased variation of rainfall patterns, etc). Second, there is the sensitivity of a system’s current condition to these hazards. Sensitivity is determined by both the environmental and human characteristics that contribute to how a system responds to exposures. Finally, the resilience of a system refers to future actions that can improve a system’s ability to cope with outside hazards. Adaptation measures are actions or processes that help improve farmers’ resilience to hazards and can include governmental policies, NGO programs and autonomous decisions made by individuals or communities. Within this paper, I will focus on climate-related hazards that are predicted to increase with climate change. Subsistence farmers will need to substantially improve their resilience to climate-related exposures in order to mitigate the negative consequences associated with future climate change.

\(^1\) The Turner et al. paper was the first time that a vulnerability framework was constructed that combined the natural science literature on ‘resilience’ with social science work on ‘human vulnerability’. By considering both major disciplines, the Turner framework allows for a more integrative approach to the vulnerability discussion [8].
Much of the vulnerability literature argues that the most effective way to improve people's resilience to shocks and stresses is through improving people's general well-being [9-11]. Household sensitivity to shocks depends on numerous compounding factors and cannot be attributed to any single environmental or social factor [5]. Improving well-being by addressing any of the multitudes of factors that negatively affect rural farmers can help them better deal with climate-related hazards. Scholars suggest a variety of general methods to improving farmers’ lives, including: improving farm productivity, providing off-farm sources of income and improving access to markets [12-15]. The climate change literature argues that it will be particularly important to focus on off-farm activities as rain-fed farm productivity becomes less reliable [16]. Agriculture will remain an important aspect of farmers’ lives, but much of the literature stresses the importance of improving the resilience of future agricultural systems to withstand climatic shocks by changing farming techniques and improving overall productivity [6].

Scholars are also examining specific anticipatory strategies to help people deal with individual climate-related shocks [17-19]. These include changes such as planting drought-resistant crops and improving flood preparedness. The literature exhibits some tension on whether to focus
climate change adaptation measures on these specific adaptation strategies or on the more general well-being improvements outlined above [20, 21].

Agroforestry’s Role

Agroforestry has been proposed as a potential strategy for helping subsistence farmers reduce their vulnerability to climate change [2, 15, 22]. Agroforestry is the intentional use of trees in the cropping system to increase farm productivity, diversify income sources and provide environmental services [23]. For example, nitrogen-fixing trees can be intercropped among rows of food crops to improve farm productivity by providing limiting nutrients to crops (see Appendix 1.1 for images of agroforestry practices). Agroforestry techniques also include the use and sale of tree crops such as fuel wood, fruit, and timber. Scholars argue that trees can also reduce soil erosion by providing long-term vegetation cover [24]. Finally, trees are considered to be more resilient to climatic-related shocks such as floods and droughts due to their deep root systems [25]. However, few studies examine the specific role agroforestry techniques can play in helping farmers reduce their vulnerability to climate change.

Current Knowledge Gaps

The scholarship on agroforestry practices suggests that agroforestry improves farmer well-being through improving farm productivity and incomes [23]. However, the current literature is largely qualitative. Scholars are calling for more rigorous analyses of agroforestry impacts, particularly on farmer-led agroforestry projects [26, 27]. Most analyses on agroforestry techniques use field experiments led by researchers to assess the effects trees have on improving farm productivity. Relatively few studies analyze farmer-led projects [28]. Farmer-led agroforestry projects are projects that allow farmers to choose the type of agroforestry techniques they use and put the responsibility of tree seedling survival in the farmers’ hands. Farmer-led projects are how agroforestry techniques are used under normal circumstances; therefore there is a need for more extensive analyses of these types of projects [27].

At the same time, scholarship on vulnerability is seeking better interdisciplinary evaluations that highlight practices that can improve farmers’ ability to cope with climate-related hazards [4, 6, 17]. This literature highlights the importance of community-led, location-specific adaptation measures that harness the extensive indigenous knowledge and adaptation techniques of local
farmers [6, 15]. Many existing analyses have not taken into account the perspectives of these local stakeholders [29, 30].

**My Contribution**

To address these knowledge gaps, I set out to evaluate whether, and, if so how, agroforestry can reduce farmers’ vulnerability to climate-related hazards. I undertook a field study of a farmer-led agroforestry development project in the Nyando District in western Kenya to assess current farmer sensitivity to climate-related hazards while also exploring how farmers use trees to help them cope with these climate hazards. I used household surveys, in-depth interviews and focus group discussions to provide both a qualitative and a quantitative dimension to my analysis [31].

My research is focused at the local level. It relies heavily on farmers’ participation in the research process to shape the questions I address in my study. Due to the local framing of my analysis, I do not touch on the potential for agroforestry techniques to contribute to climate change mitigation. As the debate around carbon trading and payments for trees as a source of carbon sequestration matures, it will certainly present an added dimension of interest for agroforestry research [22].

The Nyando District of western Kenya provided me with an excellent location in which to study climate change because the region experienced both a drought and a flood in the previous twelve months. I use these events as proxies for future weather patterns with climate change, as these types of events are predicted to increase with climate change. Scientific models also predict that the Nyando district will be one of the regions worst affected by climate change in sub-Saharan Africa because of high poverty rates and intense environmental degradation [32].

I use Turner et al.’s framework within my paper to structure my analysis in a way that is consistent with the existing vulnerability literature [8]. First, I present a review of my research methods in *Chapter Two: Methods*. Then, I explore how both the literature and the farmers define a successful life and strategies with which to improve their well-being (*Chapter Three: Conceptualizing Well-Being*). In *Chapter Four: Climate-Related Hazards*, I examine how farmers are affected by and perceive the recent climate-related hazards in their region. I also look at how differences among households affect their sensitivity to these shocks. My findings agree with the general literature that households with higher farm productivity and wealth and more diverse income sources are better able to cope with climate-related shocks. Through my analyses in *Chapters Three and Four*, I establish
an understanding of the current sensitivity of the Nyando communities to climate-related exposures. From this, I infer how the communities I studied are likely to be affected by future climatic-hazards.

In Chapter Five: The Role of Agroforestry in Reducing Farmers’ Vulnerability to Climate-Related Hazards, I explore the role of agroforestry development practices in improving the resilience of farmers to climate exposures. Through both my qualitative and quantitative analyses, I examine how involvement in agroforestry practices can help farmers improve their well-being relative to their current state. These well-being improvements come both directly through soil conservation and availability of fuel wood and indirectly through increasing income and farm productivity. I conclude that agroforestry has substantial potential to reduce farmers’ vulnerability to climate change through improving farmers’ well-being and the environmental conditions of their land. In my conclusion, I provide recommendations for how to increase the effectiveness of agroforestry projects in helping subsistence farmers adapt to climate change.

**Key Terms**

**Adaptation:** A process, action or outcome undertaken by a system to improve the resilience of the system to shock, stress or risk [17].

**Agroforestry:** The intentional use of trees in the cropping system to improve farm productivity [23].

**Climate-Related Hazards:** Threats to the system from climate-related sources. This includes both shocks, such as a flood or drought, and stresses, such as increasing rainfall variability [8].

**Climate Vulnerability:** “The degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes” [7].

**Exposure:** The frequency, duration and intensity of climate-related hazards a system is subject to [8].

**Resilience:** Future actions that can improve a system’s ability to cope with outside hazards [8].

**Sensitivity:** The amount to which a system is affected by an exposure to outside shocks and stresses in the absence of additional adaptation or outside policy intervention. Sensitivity is composed of both the human and environmental capital that influence a system’s ability to cope with hazards [8].

**Sustainable:** An action that does not lead to a decline in inter-generational well-being, either in economic, environmental or social terms [33].

**Well-Being:** Improvements in household income, assets, and food security in the face of outside stresses and shocks (modified from [52; 9]), discussed in Chapter Three.

*Table 1.1: Key terms used throughout the paper.*
Chapter Two: Methods

No one form of data collection, whether it is quantitative surveys or in-depth interviews, is infallible, as each technique has its weaknesses [31]. Much of the methodology scholarship supports the use of a mixed quantitative and qualitative methods approach to allow one form of data collection to compensate for the weaknesses in other forms [31, 34]. Scholars have found that using mixed methodologies during in-field studies are particularly helpful because it allows a study to better capture the complexities seen on the ground [34]. I chose to approach my question using a mixed methodological approach that combined household surveys, in-depth interviews, focus group discussions and field observations. I found this combination of data sources to be very helpful in creating a rich picture of the issues farmers face. In addition, the quantitative analyses provide an additional rigor to my study that is often lacking in agroforestry project evaluations [26, 27].

This chapter begins by presenting some background on the specific project that I evaluated in western Kenya. I then provide a description of both my qualitative and quantitative research and data analysis methods. I conclude the chapter with the potential limitations of this study and areas for improvement in future analyses.

Project Background

To study the effects of agroforestry on farmer well-being, I worked with three different World Agroforestry Center (ICRAF) projects. ICRAF is an international research institute associated with the Consultative Group on International Agriculture Research (CGIAR) network that focuses on agroforestry research for the developing world. The first ICRAF agroforestry project that I evaluated was implemented in 2006-2008 with three community groups in Lower Nyando (The Wkiemp Project). Farmers in these projects planted trees that have now reached maturity. The other ICRAF agroforestry project (The Comart Project) ran from 2008-2009 in both Lower and Middle Nyando. Trees from the Comart 2008 project are two years old and have not yet reached maturity.

Although implemented in different years, both the Comart and Wkiemp projects had similar objectives and provided farmers with five agroforestry and agriculture training sessions, 200-300 tree seedlings, tree nursery support and small food payments for work on community tree planting and terrace building. Recently, ICRAF staff identified two additional groups in Lower and Middle
Nyando as participants in the Comart 2010 project starting in late 2010. These two groups have not yet received any support from ICRAF and are the control groups in this study. See Appendix 2.1 for additional details.

**Site**

My research team consisted of two full-time ICRAF staff members, my translator and myself. We interviewed farmers in two different sub-locations in the Nyando District, Nyanza Province of western Kenya (see Figure 2.1). The Nyando River basin is the site of some of the most severe agricultural and environmental degradation in Kenya, in large part due to increasing population pressures on marginal lands \[35\]. Poverty rates in the Nyando District are also quite high with 65% of the population living below the poverty line in comparison to a countrywide average of 52% \[36\]. The rural poverty line in Kenya is set at US$192 per adult per year (2005 data) \[37\].

![Figure 2.1: Map of Nyando region of western Kenya. Map from Cohen 2006 [38].](image)

The first research site in Lower Nyando is located in the sub-locations East Jimo and Awach (see map in *Appendix 2.1*). This area is characterized by low gradient hills and small permanent streams at an elevation of 1200 meters. The population in this region is predominately of the Luo tribe. Agriculture is almost entirely based on small subsistence farming, with maize and sorghum dominating crop production. These staple crops are typically grown with beans or cowpeas, and most farmers also have small vegetable plots of kale and tomatoes. Tree cover is quite low in Lower
Nyando. Only 34% of household plots had any trees in the vicinity [36]. Overall, this region is characterized by low productivity, erratic rainfall and severe soil erosion.

Middle Nyando participants live in the sub-locations Ochoria, Kandege, and Siwot on the border of the Nyando and Kericho Districts (see map in Appendix 2.1). This area has medium to high gradient hills with permanent small rivers. This area used to be the land of European settlers and was redistributed to Kenyan farmers immediately following independence in the early 1960s. This area is more ethnically mixed, with Luo, Kikuyu and Kalenjins living together. Farming is primarily for subsistence, though most farmers also grow small plots of sugar cane and coffee for commercial sale. Maize is the staple crop and beans or cowpeas are frequently planted in the same fields. Farmers typically also have vegetable plots with tomatoes and kale. Tree cover is higher in this region, with more trees remaining on communal land. This block has higher productivity, cooler temperatures and more equitably distributed rainfall than seen in Lower Nyando. Average elevation is 1600 meters.

Both locations are similar in a number of basic household parameters. Average household size in this area is 6.7 members, and most household heads did not proceed past primary school education. Land size is also quite small, with average land holdings of 2.9 acres. Eighty percent of farmers in the area use animal power to plow their land, while only 3% have access to tractors. The remaining farmers hoe their fields by hand. See Figure A1.2 in Appendix 1.1 for a picture of a typical homestead in this region.

Farmers’ use of non-organic inputs varies significantly by location. Farmers in Lower Nyando have a very low rate of fertilizer use, with only 12% of households using such inputs. In contrast, most farmers in Middle Nyando use fertilizers and pesticides on their crops. Farmers attributed most of this difference to the higher level of wealth in Middle Nyando. Sex of household head also varies somewhat across locations, as more female-headed households are found in Lower Nyando. This is likely to be due to the high HIV/AIDS rates in the area, as many of these female-headed households are grandmothers taking care of their orphaned grandchildren [39]. A summary of key variables is provided in Table 2.1. This table also provides a comparison of differences across the treated and control groups used in the study.
Table 2.1: Key household parameters. Mean and standard deviations (in parentheses) for key household parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower Nyando Treated</th>
<th>Lower Nyando Control</th>
<th>Middle Nyando Treated</th>
<th>Middle Nyando Control</th>
<th>All Data Treated</th>
<th>All Data Control</th>
<th>All Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH Size</td>
<td>6.7 (2.7)</td>
<td>6.4 (2.7)</td>
<td>6.2 (3.3)</td>
<td>7.2 (2.0)</td>
<td>6.7 (2.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HH Head Sex (1=Male)</td>
<td>0.61 (0.49)</td>
<td>0.6 (0.51)</td>
<td>0.93 (0.25)</td>
<td>0.93 (0.26)</td>
<td>0.77 (0.43)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education of HH Head (Form, 0-16)</td>
<td>5.4 (4.6)</td>
<td>4.2 (4.9)</td>
<td>7.2 (3.5)</td>
<td>6.1 (4.2)</td>
<td>5.9 (4.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Size (acres)</td>
<td>2.4 (0.95)</td>
<td>1.7 (0.80)</td>
<td>3.6 (3.4)</td>
<td>3.5 (3.2)</td>
<td>2.9 (2.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holds Title to Land (1=Yes)</td>
<td>0.91 (0.23)</td>
<td>1 (0)</td>
<td>0.63 (0.49)</td>
<td>0.60 (0.50)</td>
<td>0.80 (0.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Type (1= Clay; 2= Loam; 3= Sandy)</td>
<td>1=0.65</td>
<td>1=0.53</td>
<td>1=0.07</td>
<td>1=0.18</td>
<td>1=0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2=0.16</td>
<td>2=0</td>
<td>2=0.93</td>
<td>2=0.82</td>
<td>2=0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3=0.2</td>
<td>3=0.47</td>
<td>3=0</td>
<td>3=0</td>
<td>3=0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uses in-organic fertilizer or pesticide on field (%)</td>
<td>11%</td>
<td>13%</td>
<td>69%</td>
<td>95%</td>
<td>44%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Trees</td>
<td>380 (620)</td>
<td>55 (70)</td>
<td>220 (390)</td>
<td>90 (70)</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N=</td>
<td>46</td>
<td>15</td>
<td>30</td>
<td>28</td>
<td>119</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data Collection

Survey: My research team and I conducted a survey that covered topics such as household demographics, crop productivity, farm constraints, uses of trees, food security, and perspectives on climate change with 127 households in June and July 2010. We also collected observations of household amenities, soil type, soil erosion, number of trees present, and average tree size for each household. I administered one-third of the surveys with the aid of a translator, and two ICRAF field staff members conducting the remaining surveys. See Appendix 2.2 for a detailed summary of groups interviewed.

I selected households to survey based on their involvement with an ICRAF project, as these were the only farmers in the region involved in agroforestry practices. ICRAF chose project participants using existing community group structures that are registered under the Kenyan government. Eight community groups had been identified by ICRAF staff over the last five years based on their interest in working with ICRAF, current membership size, and location within regions identified as being areas with high soil erosion rates. See Figure 2.2 for a summary of households surveyed. Due to the way in which households were selected for survey participation, there is the potential for some selection bias. I address the potential effects of this bias in my limitations section of this chapter.
In-depth Interviews: I conducted twenty in-depth interviews with farmers with the support of my translator. Questions focused on observed changes in climate, farming practices and productivity constraints, agroforestry practices, and future goals as well as how households had coped with the most recent floods and droughts. I used Weiss’ *Learning From Strangers* book as well as informal discussions with African-specialist anthropologists as a reference for the in-depth interviewing process [40].

I selected farmers for interviews using a number of methods. Interviews were conducted with all community group leaders to capture the leadership’s view of the successes and failures of their group. I also interviewed five farmers that had been identified by community leaders as having been particularly impacted by the recent floods and droughts. I conducted the remaining seven interviews with farmers that had been identified by field staff as being particularly successful or unsuccessful in their farming endeavors. I also interviewed project staff and the funding body’s board of directors to capture outside stakeholder evaluations of the projects.

Focus Group Discussions: Upon completion of all interviews and surveys, my research staff and I conducted interactive focus group discussions with seven of the eight community groups involved in ICRAF projects. The activities used images to represent uses of trees and major farming constraints identified from the survey [41]. We then segregated groups by sex and asked them to weigh the relative importance of the different tree benefits and farm problems. Groups were
segregated by sex to avoid biasing of answers due to gender dynamics within the communities. Discussion followed as the male and female groups came together to talk about the similarities and differences they saw in their weighting scheme. Focus groups ranged in size from eight to thirty members.

**Data Measurement**

I used household surveys to collect a number of key variables, such as household parameters, farm productivity, wealth and food security. All units are at the household farm level. See *Appendix 2.3* for further details.

- **Household Wealth:** To capture household wealth at the subsistence-farmer level is quite difficult, as most wealth is stored in non-cash assets [42]. I used an estimate of total livestock worth as a proxy for household wealth, as livestock is the most frequently cited indicator of one’s wealth among the Luo and Kalinjin tribes of western Kenya [43]. Livestock holdings were converted into an economic value using current local market prices.

- **Food Security:** I measured food security using two indicators, proportion of the year the household experienced hunger and the type of coping strategies used during this hunger period. These indicators were then combined using principal component analysis.

- **Farm Productivity:** I measured farm productivity by converting current seasonal crop production to economic units using average 2010 crop prices in the region.

- **Tree Biomass:** I measured agroforestry involvement by multiplying the average height of the trees by the estimated number of trees present. A different measurement of agroforestry involvement was used to check the robustness of findings and achieved similar results. (*Appendix 5.2*)

- **Soil Erosion:** Soil erosion intensity was measured using two on-farm observations, type of erosion present and intensity of observed erosion. I then combined these observations to form a nine-point scale of erosion intensity. This scaling of soil erosion is consistent with other literature on soil erosion effects [44]. An alternate measure of soil erosion was also used to verify the robustness of the findings (*Appendix 5.2*)

A summary of key outcome variables is provided in *Table 2.2*. 
Table 2.2: Key outcome variables means and standard deviations (in parentheses).

<table>
<thead>
<tr>
<th></th>
<th>Lower Nyando Treated</th>
<th>Lower Nyando Control</th>
<th>Middle Nyando Treated</th>
<th>Middle Nyando Control</th>
<th>All Data Treated</th>
<th>All Data Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Productivity</td>
<td>4,500 (5200)</td>
<td>3900 (2500)</td>
<td>15,900 (17200)</td>
<td>16,500 (16800)</td>
<td>10,000 (13500)</td>
<td></td>
</tr>
<tr>
<td>Household Wealth</td>
<td>61,700 (50000)</td>
<td>44,000 (32000)</td>
<td>59,600 (38600)</td>
<td>64,800 (48100)</td>
<td>59,600 (44600)</td>
<td></td>
</tr>
<tr>
<td>Food Security</td>
<td>-0.34 (0.65)</td>
<td>-0.19 (0.41)</td>
<td>0.03 (0.69)</td>
<td>0.42 (0.99)</td>
<td>-0.04 (0.79)</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>46</td>
<td>15</td>
<td>30</td>
<td>28</td>
<td>119</td>
<td></td>
</tr>
</tbody>
</table>

Data Analysis - Statistical

I used statistical methods in two major components of the data analysis. See Appendix 2.4 for further details.

Direct Effects: First, I examined agroforestry’s impacts on soil erosion and time spent collecting fuel wood at the household level. To estimate agroforestry’s impact on time spent collecting fuel wood, I plotted weekly time spent on collection against agroforestry involvement. A log transformation of both variables was taken to improve the linearity of the data. From the log transformation, I calculated correlation coefficients.

To evaluate agroforestry’s impact on soil erosion control, I plotted soil erosion intensity against agroforestry involvement. A log transformation of agroforestry involvement was taken before correlation coefficients were estimated to evaluate the linear relationship of the data. See Appendix 5.2 for details.

Indirect Effects: The goal of this analysis was to estimate the impacts of ICRAF’s agroforestry development projects on farmer well-being. The dependent variables used to capture farmer well-being included household wealth, food security and farm productivity. Treatment represented involvement in an ICRAF agroforestry development project, whereby households received: five agroforestry and agriculture training sessions, 200-300 seedlings, training in tree nursery management, tools and seedlings for tree nursery establishment, a small amount of food each week for involvement in community projects, and ICRAF staff support for one year.

Ideally, I would have created a random control experiment and followed farmers across time. However, due to limitations present in the field and time constraints, I used matching techniques to increase the similarities between the treatment and control groups. This process gave more weight to those households in the control group that were more similar to the treated group on basic household parameters using a statistical matching program [45]. Parameters used for matching included: household size, land tenure, household head educational level, soil type and
gender of household head, as these measures were all noted in the literature to affect subsistence farmer well-being [42].

Using the matched data, linear regressions were used to evaluate the treatment’s impact on the outcome variables, accounting for potential regional differences between the two sub-locations and for potential different treatment effects across the two sub-locations [46]. This analysis was run again after incorporating the basic household parameters into the regression as well. Similar results and statistical significance were found using this method, showing the robustness of my findings.

During statistical analysis, I used 116 out of the initial 127 surveys. Eight households had received seedlings in 2008 but no training or additional ICRAF support and, therefore, did not fit into any of the existing categories for analysis. Three farmers involved in existing ICRAF projects were substantially wealthier than average participants due to off-farm income. These farmers were omitted because they were substantially different from all other households in the area. See Appendix 2.4 for further details.

**Data Analysis - Other**

I analyzed my extensive field observations, interview notes and focus-group discussion dialogue by inputting my notes into my computer then categorizing them by theme. I tagged major topics within my notes, which allowed me to later compare different farmers’ views on key themes in my paper [40].

**Limitations**

This study contains a number of limitations due to the nature of field research and the limited amount of time available to conduct research. I recognize that a random sampling of households involved in agroforestry practices would have reduced potential for biases in this study. I attempted to correct this potential bias through matching households on basic household parameters and comparing findings to general population surveys. However, some selection bias may still exist. Such biases are a potential hazard in any observational study.

Future studies on agroforestry’s role in helping farmers adapt to climate change should include farmers that have been involved in agroforestry for a longer period of time. This study addressed farmers who had only been practicing agroforestry techniques for a maximum of four years. Because trees take several years to mature, it is likely that many effects of the agroforestry system had not yet been realized. However, the findings of this study are not irrelevant, as much of
the literature on agroforestry systems have highlighted the need for further research on the short-
term impacts of agroforestry systems [47].

Due to limited availability of rainfall and temperature data, objective climate measures were
not available to verify farmers’ perceptions on climate changes over the last thirty years. It would be
beneficial for future studies to compare current farmers’ perceptions on climate change with
scientific records.

Farmers may have also over- or understated responses because of perceived benefits they
may obtain from providing the ‘correct’ answers. To limit these potential biases, preliminary
discussions with community groups clearly stated that farmers would not receive any benefits
contingent on their answers to the survey questions. This statement was repeated at the beginning
of each survey.

**Generalizability of Study**

<table>
<thead>
<tr>
<th></th>
<th>Lower Nyando</th>
<th>Middle Nyando</th>
<th>Rural Nyanza</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collected Data</td>
<td>ICRAF Baseline</td>
<td>Collected Data</td>
</tr>
<tr>
<td>HH Size (num people)</td>
<td>6.7 (2.6)</td>
<td>8</td>
<td>6.4 (2.4)</td>
</tr>
<tr>
<td>Male-Headed HH</td>
<td>.60</td>
<td>.71</td>
<td>.92</td>
</tr>
<tr>
<td>Hold Title to Land</td>
<td>.93</td>
<td>.96</td>
<td>.61</td>
</tr>
<tr>
<td>Farm Size (in acres)</td>
<td>2.32 (1.38)</td>
<td>6</td>
<td>3 (1.54)</td>
</tr>
<tr>
<td>Community Group Membership</td>
<td>1</td>
<td>.58</td>
<td>.79</td>
</tr>
<tr>
<td>HH Head Education</td>
<td>.32</td>
<td>-</td>
<td>.16</td>
</tr>
<tr>
<td>- None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Primary</td>
<td>.50</td>
<td>-</td>
<td>.59</td>
</tr>
<tr>
<td>- Secondary</td>
<td>.13</td>
<td>-</td>
<td>.25</td>
</tr>
<tr>
<td>- Post Secondary</td>
<td>.05</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>N=</td>
<td>60</td>
<td>177</td>
<td>56</td>
</tr>
</tbody>
</table>

Table 2.2: Generalizability of study. A comparison of basic household parameters across different data sets to evaluate the similarity of sample used for analysis. Data from my 2010 survey was compared to a baseline population survey conducted in each sub-location in 2008 by ICRAF staff, and the 2003 National Kenya Demographic and Health Survey for rural Nyanza Province households. [36, 48] SD included in parenthesis where available. HH= Household head.

From the summary statistics presented in Table 2.3, it is clear that the sample drawn for my
analysis closely matches general population data on basic household parameters for the region.
Households in my sample are typically larger than the province-wide averages for rural Nyanza, but
are quite similar to the household size trends in the sub-locations studied. There are substantially
more male-headed households in Middle Nyando as compared to Nyanza province, but again, the proportion of these households in my study matches closely to that of ICRAF’s baseline population survey. Educational attainment of household head is also fairly equivalent across all surveys.

My sample has a very high proportion of small farm sizes as compared to the ICRAF baseline study. This difference may in part be due to the inaccuracy of reporting land size in my survey, as many people did not know the total size of all of their farm plots. Community group membership was higher in my study, which is to be expected since my sample was drawn from households who had been involved in a community organization.

Overall, my sample is consistent with the basic household parameters of other population surveys in the region, especially with surveys that focus on the particular region of Lower and Middle Nyando. My sample will be especially useful for generalizing to populations with small land holdings who are involved in community organizations in sub-Saharan Africa.
Chapter Three: Conceptualizing Well-Being

In this paper, I set out to establish how climate change affects farmers and how agroforestry practices can help reduce farmers’ vulnerability to climate change. Before I am able to assess how climate-related hazards impact farmers, I first need to define what exactly is vulnerable to these events. It is not just human mortality rates that will be affected by climate change; it is people’s way of life. I use human well-being to refer to the object that is affected by and vulnerable to climate change as this broader concept encompasses the many facets of people’s lives that are affected by climate-related hazards. This chapter sets out to establish how the literature and the farmers interviewed conceptualize well-being. From this review I establish a definition of well-being to use as a basis for future analyses that assess the effects of climate change and agroforestry projects on human well-being.

I begin here by reviewing the literature’s attempts to establish a concept of human well-being. I then explore how the literature attempts to measure changes in well-being. I also briefly review and bring into my analytical framework the variety of other terms and concepts used in the literature that relate to well-being. Next, I present my findings on the way farmers define well-being and the ways in which they believe that they can make improvements in their life. Finally, I compare the literature and farmers’ perspectives to provide a context-specific definition of well-being and a list of key determinants that contribute to well-being.

Literature Review

Achieving well-being or a similarly acceptable quality of life is a fundamental goal in most development projects focused on poverty alleviation [49]. The literature on well-being distinguishes between the constituents and determinants of well-being. “Constituents” are generally agreed to be the components that define well-being such as happiness, health and positive relationships with others. But scholars have struggled to define these constituents in a technically rigorous way [49, 50].

Sen, a leader in this debate, defines well-being as the ability of a person to meet his or her basic human needs, be able to function effectively in his or her social context, and have the capability to make choices in his or her life [51]. Nussbaum further develops this idea by creating a concrete list of constituents that make up a person’s well-being. These include: bodily health, bodily integrity, ability to express emotions, control over one’s own environment, etc. [52]. Constanza et
also argue for a holistic approach to human well-being that incorporates both subjective measures of happiness and empirical social, economic and health indicators [49, 52]. Nussbaum’s complete list, or some variations of it, incorporates what much of the literature defines as the key constituents of well-being.

“Determinants”, on the other hand, are factors that produce or cause improvements in well-being. Examples include clean water, access to knowledge and capital, and wealth. Most scholars agree that historic measures of determinants of well-being, like per capita GDP, do not focus enough on the diversity and complexity of well-being at the household level [53, 54]. To address this, the French government asked Stiglitz and Sen to compile a comprehensive index of economic progress and social well-being [54]. Their conclusions delineate the following determinants as key to improving well-being: income/consumption/wealth; health; education; political voice; social connectivity; environmental conditions and insecurities faced [54]. These indicators largely capture the main determinants cited by other work on the topic [9, 53, 55, 56]. More and more indices are including environmental components to their list of well-being determinants, as they recognize the importance of environmental health for long-term sustainability [55].

In addition to the major determinants covered by Stiglitz and Sen, many scholars also emphasize the importance of access to land as a key contributor to improving well-being [57]. The literature also overwhelmingly supports the diversification of sources of income as a means to improve well-being among rural dwellers [9, 10, 57]. Scholars have also cited enhancing the knowledge and skills of individuals, improving access to markets and providing access to credit as effective ways to improve well-being [10, 57]. Research points to the importance of developing context-specific determinants of well-being, because they often differ substantially across regions and cultures [53, 56, 58].

Comparing Stiglitz and Sen’s list with the earlier work of Nussbaum shows the difference between constituents of well-being and well-being determinants [52, 54]. Stiglitz and Sen’s list of determinants are concrete topics that can address directly [54]. Constituents, on the other hand, are defined as the ultimate goals in life that all people fundamentally share [52]. Dasgupta argues that by improving the determinants laid out by Stiglitz and Sen, one progresses towards improving their general well-being [50].

Human livelihood security is a concept closely tied with this concept of well-being. Chambers and Conway (1992) define human livelihood as “the capabilities, assets (stores, resources, claims and access) and activities required for a means of living.” [9]. Livelihood security is then
defined as “a family’s ability to maintain and improve its income, assets and social well-being from year to year” [53]. In this sense, security refers to the ability to maintain a basic standard of living even in the face of outside shocks. The concept of livelihood security is often used to delineate a minimum level of livelihood security that should be the goal for all households [57]. The concept of livelihoods also has a similar differentiation between constituents of and determinants of livelihood security. However, the literature around livelihood security is not as fully developed as the scholarship around well-being.

Below, I examine how the farmers I interviewed conceptualize well-being and improvements in their life. Using these results in tandem with the literature on the topic, I then present the framework I use in this paper to ground my discussions of farmers’ vulnerability.

**Findings- Definitions of Well-Being from the Farmers’ Perspective**

When asked about ways to better their lives, farmers interviewed were most interested in ways to improve their household’s food security. To do this, farmers were interested in opportunities to start small business ventures or obtaining credit to purchase farm implements to improve their productivity. Farmers also expressed interest in opportunities to improve their agricultural knowledge and to learn about alternative income opportunities.

When asked what they would do with the extra income from new business ventures, farmers report either wanting to purchase more food to diversify their families’ diets or to invest in livestock. Investing in livestock in this area primarily serves as a form of savings used during periods of food insecurity, because the animals can be sold or consumed when food is scarce. Farmers also report wanting to improve farm productivity in order to become more self-sufficient in food production. Many farmers remember times that their family could subsist solely on food from their own farm, and could thus spend additional income on household improvements and education. Now, many of their household expenditures are for food, leaving little money for unexpected illnesses, children’s school fees and household and farm improvements.

Underlying these farmers’ goals to improve their agricultural yield and income was their desire to improve their own food security, particularly when faced with outside shocks. Food security, as defined by the farmers, is the ability to obtain an adequate and diverse diet for all household members throughout the year, without being forced to use long-term savings to purchase food.
It is only after a household is relatively food secure that it begins investing in long-term processes for improving other aspects of their well-being. One woman, who has a successful small business, reports that her first objective after obtaining additional income from her store was to deal with the chronic food insecurity of her household. Only after there was enough food did she begin investing in other things, such as sending all of her children to school, obtaining a safe source of drinking water and finally improving basic household amenities. This woman’s story is similar to many that I heard, and clearly outlines the order of priorities that most farmers share when they set out to improve their households’ well-being.

This stepwise process to improving well-being is clear when comparing Lower and Middle Nyando farmers’ goals. Lower Nyando farmers are still very food insecure and thus rarely focus on any goals not related to improving their household food supply. On the other hand, some Middle Nyando farmers report feeling food secure throughout the year and discuss goals related to expanding landholdings, improving their children’s education and investing in long-term projects to ensure financial security. The clearest pathway farmers see to ensure improvements for their families is through improving and diversifying their incomes and increasing farm productivity.

When I urged farmers to expand on their life goals, most people had a very difficult time providing answers outside of the improvements outlined above. In an interview with a fluent English-speaking elder, I asked if this unwillingness of farmers to discuss big-picture goals was due to my outsider status or the language barrier. He explained that people in this region “just don’t see beyond the day-to-day.” Other community leaders I interviewed about this topic had similar responses and explained that people are unable to plan into the future because most are struggling with meeting their family’s daily needs, particularly in years in which they experience significant outside shocks such as floods or droughts.

Although they did not expand on personal goals, people did have a picture of what characteristics contributed to a successful household in the area. A successful household owns its own land, farm tools and oxen, is mostly food self-sufficient throughout the year, has at least one steady source of off-farm income, all of its children are attending school and it has a healthy store of livestock. Most farmers agree that secure households are typically male-headed with both the husband and wife present. A majority of farmers interviewed also used the way in which a household is able to deal with shocks or stresses to define a successful household. During times of stress, successful households are food secure for a longer period of time, often giving support to their neighbors and family. There was some small variation in this definition of a successful
household, but overall, there was a general consensus among farmers on the determinants of a successful household in this area.

Farmers also report that, over the last five years, they have put more emphasis on the environmental conservation of their land. They have come to realize that the quality of their life has significantly declined as soil erosion has lowered farm productivity. As one farmer explained, “soil is our livelihood” and they have begun to see the long-term impacts that their unsustainable agriculture practices have on their land. Even without the support of non-government organization (NGO) or government-led projects, farmers in the area are banding together to begin soil conservation practices, showing that environmental conservation is perceived as a key way through which communities believe they can improve their well-being.

**Findings—Quantitative**

From my qualitative assessment, I found that farmers placed a strong emphasis on food security. To further examine farmers’ insights into what contributes to improving food security, I used my quantitative survey data to analyze these relationships. Farmers listed household wealth, having a male-headed household and owning one’s own land to be key factors in improving food security. My quantitative analysis suggests that these factors are in fact correlated with improved food security. Controlling for other key variables, my findings show that a household in the 75th percentile of farm productivity is 11.2% more food secure than a similar household in the 25th percentile of farm productivity (p=<.0001). See Table 3.1. This analysis assumes all other variables are held at their mean values. See Appendix 3.1 for details on methodology. I also find that a household in the 75th percentile of household wealth is 6.5% more food secure than a similar household in the 25th percentile of household wealth (p=.002). Both household wealth and farm productivity are defined and measured independently of food security. No hidden co-determinants due to methodological measurement influence the strength of the relationships observed.

These findings vary substantially between Lowe and Middle Nyando. For Lower Nyando, farm productivity is clearly most significantly correlated with food security, as moving from the 25th to 75th percentile in farm productivity improves food security by 25.6% (p=<.0001). In Middle Nyando, farm productivity only improves food security by 11.8%, still a significant correlation. These findings agree with my qualitative data on the differences between the two regions, as Lower Nyando farmers are, on average, more subsistence-based than their Middle Nyando counterparts. Wealth, on the other hand, presents far more of a correlation with food security in Middle Nyando
as compared with Lower Nyando. In Middle Nyando, moving from the 25th to 75th percentile in household wealth is associated with a 12.8% increase in food security (p=.003), whereas for Lower Nyando the improvement is only 2.8%, and this correlation is not statistically significant (p=.14). Again, these findings agree with my qualitative results, as more Middle Nyando farmers report being tied to off-farm income opportunities than their Lower Nyando counterparts.

<table>
<thead>
<tr>
<th>Numbers in % Improvement</th>
<th>Farm Production</th>
<th>HH Wealth</th>
<th>Male-Headed HH</th>
<th>Education of HH Head</th>
<th>Hold Deed to Land</th>
<th>Title of Income Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Nyando HH Food Security</td>
<td>25.6 (p&lt;.0001)</td>
<td>2.8 (p=.14)</td>
<td>5.7 (p=.22)</td>
<td>.25 (p=.6)</td>
<td>6.5 (p=.054)</td>
<td>.6 (p=.25)</td>
</tr>
<tr>
<td>Middle Nyando HH Food Security</td>
<td>11.8 (p=.005)</td>
<td>12.8 (p=.003)</td>
<td>33 (p=.021)</td>
<td>1.1 (p=.258)</td>
<td>4.0 (p=.61)</td>
<td>.1.9 (p=.711)</td>
</tr>
<tr>
<td>All Households Food Security</td>
<td>11.2 (p&lt;.0001)</td>
<td>6.5 (p=.002)</td>
<td>12 (p=.09)</td>
<td>.54 (p=.21)</td>
<td>5.5 (p=.20)</td>
<td>.4 (p=.84)</td>
</tr>
</tbody>
</table>

Table 3.1: Variables affecting food security. % improvement in food security due to different components of livelihoods. Farm production shows the effect of moving from the 25th to 75th quartile of farm productivity; HH Wealth shows the effect of moving from the 25th to 75th quartile of household wealth, measured in livestock holdings; Education of HH Head measured in increasing educational attainment of HH head by one year; # of Income Sources measured in increasing income diversity by one source. HH=Household. Lower N= 60; Middle N=56; Total N=116.

Other variables used in the regression are also correlated with household food security. Families with male household heads experience 12% higher food security than female-headed counterparts (p=.09). Although not statistically significant, increased educational attainment of household heads, the holding of the title deed to one’s land and diversification of income sources also show positive correlations with improving food security as well (Table 3.1). Household heads with one additional year of schooling is correlated with a 0.54% increase in food security. Holding the title deed to one’s land correlates with a 5.5% increase in food security. Number of income sources has the least significance in explaining household food security, but there is also a positive trend. The only variable that is negatively related to household food security is household size, as would be expected with a larger number of mouths to feed. See Appendix 3.1 for a detailed analysis of the methods used for these calculations.

It is also clear from this analysis that the gender of household heads and land tenure have a significant effect on food security. To further analyze this trend, I ran the same regression while holding both gender of household head and land ownership constant. Within each subgroup (male-headed household, no title; female-headed household, no title; etc), I found the same general trends as described above.

In analyzing the data further by sub-location it was clear that there are substantial differences in the effects of household-head gender on food security. The large difference in the male-headed
household figures between the two locations may in large part be due to the higher frequency of female-headed households in Lower Nyando. Although it is unclear exactly why there are more female-headed households in Lower Nyando, the literature and local development practitioners blame the HIV/AIDS epidemic, which is a particularly large issue among the young men in this region [39].

From this quantitative analysis, I found that the variables farmers expressed as important in ensuring food security do correlate with measurable changes in household food security. This analysis also points out the importance of household gender and land ownership on food security. From this finding, one may question why development projects do not focus more on these determinants. However, agricultural development programs cannot ensure land tenure or gender dynamics, as these are very complex issues affected by a multitude of factors including governmental policy, historic trends, and disease patterns. What is more relevant to agricultural development programs are my findings that farm productivity and household wealth are important indicators of food security, regardless of land tenure or household-head gender status.

**Discussion**

From my interviews with farmers, I derived a number of primary and secondary determinants of well-being. First and foremost, being food secure throughout the entire year is the primary goal for the farmers interviewed. After food insecurity is dealt with, farmers look to provide benefits to future generations through emphasizing the education of their children and securing or expanding their land holdings. Secondary determinants of well-being included: access to a market, diverse income sources, improved access to health facilities and clean water sources, environmental conservation and general home improvements. No farmers mentioned “improving happiness” or “finding more time for leisure” or other subjective emotional forms of well-being.

Farmers’ strategies to improve their well-being agree with those suggested by scholars, as both groups highlighted the need to increase income flow and diversity. Farm productivity also remains an important pathway for farmers to ensure food security. Farmers strongly supported Chambers’ argument for improving access to knowledge, particularly agricultural skills and techniques [9]. My findings that show farmers’ emphasis on environmental conservation support Hahn’s call to incorporate environmental components into future well-being measures [55]. It is encouraging that the literature has prioritized the same key pathways farmers have noted to improve
farmer well-being because, often in comparing farmer and literature perceptions, one finds large discrepancies [59].

Despite these similarities with the literature, I found that farmers weigh the different determinants of well-being very differently than how the literature calculates such indexes. From my analysis, food security is by far the most important self-reported indicator of a well-being in this region. None of the indexes of well-being reviewed in the literature included food security as such an important factor. This difference between local and academic perspectives highlights the importance of conducting location-specific evaluations of livelihood indicators, as suggested in some of the literature [53, 56, 58].

In their discussions, farmers also completely ignored the distinction between determinants and constituents of well-being. Farmers never focused or even mentioned Sen’s and Nussbaum’s abstract goals of well-being such as leisure, freedom and political participation [51, 52]. Instead, farmers only discussed the processes, or determinants, through which to improve their material lives. Therefore, in this paper when discussing “well-being”, I refer to these tangible determinants of well-being.

For the same reason, I chose to not use the concept of livelihood security in my discussion of farmer well-being. The literature on livelihood security focused on an absolute level of well-being that needs to be obtained, even in times of stress and shock, to ensure livelihood security [57]. Farmers do not define well-being in absolute terms or as fixed goals they are trying to achieve. Instead, they looked at relative improvements in their lives. One aspect of the livelihood discussion that farmers did bring up is the need to reduce their vulnerability to outside shocks. Therefore, within my conceptualization of well-being, I include a qualifier that necessitates improvements in well-being in the face of these outside shocks. The general framework of livelihood security was not relevant in the context of this analysis because the concept of a minimum level of livelihood security did not resonate with the farmers’ views.

Using the ideas expressed by farmers, I modified, for the use of my analysis, the definitions of well-being presented in the literature. I define well-being as improvements in household income, assets, and food security in the face of outside stresses and shocks (modified from [9, 53]). Many farmers interviewed also understand the importance of making these improvements in an environmentally sustainable way that can leave natural resources in a state to support future generations.
This definition is unique because it specifically stresses the importance of food security for farmer well-being, a concept very important to the farmers though not prevalent in the literature. In addition, it takes into account the need to achieve well-being improvements while exposed to climate-related hazards. Finally, by focusing solely on well-being determinants and not constituents, this definition uses a framework that can reflect the thought process of the farmers themselves. These adjustments to the accepted definition of well-being show the importance of using both established literature and participant’s perceptions to most accurately capture the local concept of well-being.

Throughout the rest of the paper, I use this discussion of well-being to frame how farmers can most effectively reduce their vulnerability to climate-related hazards. I continue with this well-being framework during my assessment of how agroforestry can help farmers mitigate their vulnerability to climate change, when I use food security, farm productivity and household wealth as key indicators of well-being improvements.
Chapter Four: Climate-Related Hazards

How communities cope with climate-related hazards can give us insight into their ability to deal with future changes brought on by anthropogenic climate change [60]. Climate change is likely to exacerbate existing poverty and food insecurity, especially as population pressures continue to increase in the developing world [61]. Morton (2007) calls for a more interdisciplinary combination of scholarly fields and farmer perceptions to understand the effects of climate change on the complex systems of rural farmers [6].

This chapter sets out to assess farmers’ perceptions of climate-related hazards and the effects of recent climate-related shocks on farmer well-being. Climate-related hazards, as I defined in the introduction, consist of both climate-related shocks, such as floods and droughts, and longer-term climate stresses, such as increasing rainfall variability. Farmers grouped climate-related hazards into three major topics: climate variability, droughts, and floods. I focus on these three major types of hazards, though I understand that other changes are also expected to occur. In this chapter, I follow Turner et al’s (2003) framework to outline my analysis [8]. The findings in this chapter can help illuminate how farmers will be affected by future climate-related hazards and provides location-specific information on adaptation opportunities.

First, I briefly summarize how continued emission of greenhouse gases is expected to increase farmers’ exposure to climate variability, floods and droughts. I compare these findings with farmers’ perceptions of current climate trends. I then assess how sensitive farmers are to exposures to climate-related hazards by assessing how farmers dealt with the most recent flood and drought in the area. Finally, I look at future adaptation strategies that have the potential to reduce farmers’ vulnerability to climate-related hazards, both in the literature and from the farmers’ perspective. I build off the well-being discussion outlined in the previous chapter to make these adaptation recommendations.

I show that climate change has already begun to affect traditional climate patterns and is expected to significantly increase the frequency and severity of droughts, floods and rainfall variability. I find that farmers’ perceptions of these climatic changes agree with the trends presented in the literature. My findings also highlight the unsustainable ways that farmers are currently coping with climate-related hazards and the need for further adaptation measures.
Through this analysis, I conclude that the most effective way to reduce the vulnerability of farmers to future climate-related hazards is through improving farmers’ general well-being, particularly through increasing household farm productivity and off-farm income opportunities. Some scholars have argued for supporting very specific adaptation techniques such as dams for flood control or changing crop varieties. Although specific strategies will undoubtedly be helpful, I argue that it is most effective to focus on general improvements in well-being and allow farmers to invest in specific adaptation measures as they see fit.

**Section One: Increasing Exposure to and Farmers’ Perceptions of Climate-Related Hazards**

In this section, I provide a general review of the literature on the predictions for future changes in climate over the next fifty to one hundred years. I pay particular attention to the climate effects that are likely to be felt in Eastern Africa and are thus affecting the farmers surveyed in this analysis. It is important to keep in mind that there is very high uncertainty around the scientific predictions of specific future climate changes associated with carbon dioxide emissions. In addition, climate change is expected to have vastly different effects on different regions of the world. I only focus on rainfall variability, droughts and floods. Other changes, such as increasing temperatures and changes in the length of growing season, are not examined in this study, as it was not possible to observe the impact of these long-term changes on farmer well-being in the short duration of my field work.

After a literature review of climate predictions, I present farmers’ observations of these climatic trends. I also analyze current farmers’ understanding of the global warming phenomenon. Through comparing and contrasting the current literature on climate change with farmers’ perceptions, I find that farmers are very sensitive to the climate variations the literature predicts will become more frequent.

**Literature Review**

According to the Intergovernmental Panel on Climate Change (IPCC), average global temperatures have already risen by .6 degrees Celsius due to anthropogenic forces, and scientists expect a further 1.5 to 3 degrees of warming by the end of the century [5]. Climate change will have a disproportionately large effect on developing countries that still rely heavily on agriculture and
other ecosystem services [2]. Scholars expect that climate change will reduce agricultural productivity in the developing world by 10-20% by 2050 because of changing rainfall patterns, warming temperatures, increases in the frequency of extreme weather events, and more prevalent crop pests and diseases [3, 62]. All of the studies reviewed have a very high error term in their predictions of future climate changes, particularly at the local level [1]. Despite this potential for error, according to the World Bank, “scientific evidence about the seriousness of the climate threat to agriculture is now unambiguous” [2].

Rain Variability: Warmer temperatures cause increased rain variability by increasing atmospheric moisture and altering the cycling of water in the atmosphere [63-65]. Studies also predict abnormal rainfall due to warming sea surface temperatures and changes in ocean circulation patterns, as these factors play a large role in continental rainfall patterns [5, 66, 67]. Hulme et al. (2005) have already observed an increase in rainfall variability in much of the African continent [68]. Hulme et al. (2000) expect a 50-100% increase in rainfall across Eastern Africa and rainfall reduction in the Northwest and Southern parts of Africa by 2100 [69]. On a more local scale, Mati (2000) predicts there will be a shift in rainfall distributions across Kenya, with an increase in intensity of the short rain period (October to January) and a decrease in rain during the long rain period (April to July) [70]. Due to the numerous factors influencing rainfall patterns, predicting future rainfall changes remains difficult [69, 71]. Nevertheless, the literature agrees that, overall, increased weather variability in the developing world will negatively affect agricultural productivity [4].

Drought: Definitions of drought vary by source, but it is generally accepted that a drought “is characterized by a lack of rainfall compared with an expected amount for a given period of time” [72]. Because land degradation, overgrazing, deforestation, and unfavorable rainfall distributions can exacerbate crop failure, the meteorological definition of drought alone doesn’t effectively capture all of the effects on the ground [73, 74]. In this paper, I use Slegers’ definition of “agricultural drought” which includes any event that causes drought-like plant stress due to reduced or untimely rains [73].

Since 1970, drought frequency and intensity have been increasing, especially in Africa [75]. Climate change models predict drought intensity and frequency will continue to increase with warming temperatures, especially over mid and low latitudes [5, 75, 76]. Using the IPCC’s A2 scenario to predict warming trends, Burke et al expects to see the proportion of land area in extreme
drought to increase from 1% to 30% by 2090 [77]. Li predicts that the intensities of drought, as measured by the reduction in river flows, will double by 2090 [76]. One key limitation to these predictions is that they rely heavily on local precipitation models, which still aren’t entirely reliable [75].

**Floods:** The flood predictions I reviewed all agree that there will be an increase in frequency and severity of floods as the climate warms [5, 78, 79]. Kleinen and Peschel’s work predicts that the Amazon basin will experience 50-year maximum flows every 3.6 years by 2080 [78]. However, as Kleine and Peschel note, flooding hazards will be very heterogeneous across different river basins, with a few major basins seeing a decrease in flooding frequency. Locally, Notter (2007) predicts that annual river flow on Mount Kenya will increase by 26% with a heavy increase in the rainy season and decrease at all other times, leading to a substantial increase in flooding potential [80]. There has been no observable trend of increased flood frequency around the world over the last 100 years [81]. Most studies caution that their predictions have a high degree of uncertainty, as it is difficult to incorporate flood predictions into large-scale climate models [5, 66, 79].

Despite the intense effort of the scientific community to produce accurate trends about the state of future climates, there remains much uncertainty in the specifics of the results presented above. As Conway (2009) puts it in his extensive review of the state of climate change science in Africa, “there is still great uncertainty about the key climatic processes and their consequences” [10]. Although the scientific community agrees on the general trends presented here, it is necessary to remember the high level of uncertainty in the details of current climate predictions.

**Findings: Perceptions on changes in climate**

In my surveys, many farmers noted a shift in the climate, with 88% of farmers interviewed noticing a negative change over the past ten years. The most common change observed was a shift in the rain patterns, with farmers complaining that rainfall has increased in variability and decreased in frequency. Other shifts in climate mentioned included: warmer temperatures, an increased prevalence of disease and pests, more frequent and heavy winds and storms, and more clouds. For the small proportion of farmers who saw a positive change in climate, most cited the most recent heavy rains in Middle Nyando.

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2 The IPCC A2 emissions scenario predicts high population growth, minimal collaborations across countries and slow technological improvements
Table 4.1: Farmers’ perception of recent changes in climate from household surveys. All numbers are in percentages. More than one type of negative change could be listed. N=116.

Most farmers interviewed noted changes in normal rainfall patterns beginning in the early 1990s. Over the last five years, farmers noticed rainfall variability increasing substantially, as rains fail to come more frequently or come suddenly at abnormal times of the year. All farmers have also noticed more frequent droughts in the last ten years as compared to twenty to thirty years ago. Farmers identified droughts as any time that poor rains resulted in failed or severely stunted crops. Flood trends were not mentioned, as floods in the area have historically been very infrequent.

Perceptions of changes were mostly consistent across both sub-locations of research. Middle Nyando residents were slightly more concerned with increased rain variability, as they noticed more frequent droughts in an area that is historically known for consistently good rains. Lower Nyando residents also noticed more frequent droughts, but they consider this observation to be more typical of the arid region in which they live. Lower Nyando farmers complain of a decrease in predictability in the short rainy season in September, while many farmers in Middle Nyando noticed a new short rainy season in late September that had not previously occurred.

**Findings – Perceptions of Global Warming**

Overall, the majority of farmers I interviewed are familiar with the concept of human-induced climate change. Farmers involved in an ICRAF agroforestry project were more likely to have heard of global warming, as 85% of project participants had heard of global warming but only 72% of non-project participants were familiar with global warming (p=.03). When asked about the cause of global warming, 56% report human activities, while 21% of farmers said they did not know and 14% blamed God. Only a handful of farmers noted gas emissions from factories or other countries as a major source of the warming. The vast majority of people heard of global warming on the radio. For those people who believe that something can be done about climate change, 85% cite the planting of trees as a potential solution. There was minimal variation in this response across project and non-project participants. Almost all farmers heard of tree planting as a solution to climate problems on the radio from the Kenyan government.
All Numbers in % | Heard of Global Warming | Global Warming is human caused | Believes something can be done collectively | Believes something can be done personally
---|---|---|---|---
Control Group | 72 | 54 | 75 | 69
Project Participants | 85 | 56 | 87 | 79
All Surveyed | 80 | 56 | 83 | 76

Table 4.2: Farmer perception of global warming. All numbers are in percents. N=116

Discussion

In response to open-ended questions on changes farmers have seen in their environment, the farmers I interviewed noted increased variability in rainfall patterns, more droughts and warming temperatures over the last thirty years. These observations are consistent with other studies on farmer perceptions of climate changes in sub-Saharan Africa [82]. Due to lack of meteorological data in the area, I was unable to compare these observed trends to weather records. There are mixed findings among studies comparing farmer perceptions to meteorological trends. Most studies agree that farmers overemphasize recent changes in the last five years when discussing observations in long-term climate trends [82]. However, a study in Kenya similar to mine found that farmer’s perceptions of increasing variability of rains and more frequent droughts matched season-specific meteorological data [83]. Although I was unable to compare my findings with outside measurements, my findings support other data-driven studies that recorded increases in rainfall variability, droughts, and warming temperatures over the last 10-20 years in this region [84]. The farmers’ detailed perception of these climatic changes show how dependent farmers are on weather patterns.

Droughts, as defined by farmers interviewed, include a wider range of events than those defined by meteorological data alone. This finding is consistent with Slegers’ (2008) assertion that, when considering the social impacts of drought events, droughts should not be defined only as a physical event [73]. Farmers’ perception that droughts have been increasing in frequency over the last ten years is also consistent with other research [75, 85].

Awareness and acceptance of human-caused climate change among these farmers in rural Kenya is also quite high. This high level of awareness may be in part because people closely tied to agriculture have a much larger vested interest in climate change as they depend on the climate for their livelihood. In addition, the Kenyan Government has run a number of extensive educational campaigns around tree planting and climate change to encourage reforestation projects, as the

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3 In comparison, only 57% of Americans believe that global warming is occurring, and only 36% believe that the changes are human caused (2009 data) [151]. European countries are typically more aware than their American counterparts, with 88% of people in France seeing global warming as a major problem [152].
government believes education of the public is the most effective way to promote environmental conservation [86]. From my results, it is clear that the Kenyan Government’s message is reaching the people.

Regardless of the root of farmers’ understanding of climate change, this knowledge may help these farmers adapt to future climate changes. Studies have shown that farmers’ understanding of climate change is a necessary precondition for households to invest in adaptation strategies [82]. Knowledge of global warming may have confounded my results on observed climate trends, as farmers know that many people are talking about changing weather patterns [87]. However, I believe this effect was small, as those who had not heard of global warming still noted substantial changes in the climate over the past twenty to thirty years.

**Section Two: Sensitivity of Farmer Well-Being to Climate-Related Hazards**

The above review indicates that farmers perceive and scientists agree that climate change is happening and projected to get worse. It is important to understand how such changes could affect farmers’ well-being. I review below the literature on the current impacts of climate-related hazards on subsistence farmers and how farmers cope with these shocks. I assess the sensitivity of households in my study to climate-related hazards by examining how farmers were affected by the most recent 2009 drought and 2010 flood. Finally, I examine the current coping strategies used by farmers interviewed to deal with these climate-related hazards. I examine these impacts in order to preview how sensitive farmers will be to future climate changes if no adaptation measures are undertaken.

My findings show that climate-related hazards significantly increase household vulnerability through reduced farm productivity and household food security. Although farmers have been able to deal with past droughts and floods, the increasing frequency and intensity of climate-related hazards is forcing farmers to engage more frequently in unsustainable coping strategies such as consuming seeds reserved for planting and selling farm implements. These circumstances highlight the need to help farmers improve their resilience to climate-related hazards, a topic I address in *Section Three.*
**Literature Review**

Climate change exposes farmers to a variety of hazards. Increasingly erratic rainfall patterns create difficulties for farmers who rely on seasonal cues to plant their crops [88]. For example, many farmers use animal behavior patterns to predict when the rains are coming, but climate change has significantly altered the synchronization of these natural events [89]. Delayed planting has huge impacts on farm yields. Maize production in Zambia decreased by an average of 1.5% each day that planting was delayed [90]. For the 96% of farmers in sub-Saharan Africa without access to irrigation, changes in rainfall patterns have huge effects on farm productivity [10].

Droughts also have major economic and social implications, especially in the developing world where national GDPs rely heavily on agricultural production. The 2000 drought in Kenya cost the country an estimated 16% of GDP [91]. These negative economic trends are even more pronounced on the local scale, with maize productions in the Nyeri District of Kenya falling from 1.8 tones/ha to .2 tones/ha during the drought of 2000 [91]. Ahmed found through a series of case studies that droughts reduced food consumption between 30 and 70%, decreased income levels across all income classes, increased the number of families living in poverty by as much as 69%, and reduced school attendance among children [92]. Droughts also put higher pressure on natural resources, with Mogaka finding that deforestation increases substantially during drought periods due to increased charcoal production, agricultural expansion, logging and forest grazing [91].

Of all natural disasters, floods are the most frequent and have huge effects on people’s lives [5, 93]. In the 1997-98 Kenyan flood, 300,000 people were displaced and the economic cost of the flood was estimated at over 11% of Kenyan GDP [91]. Damage associated with floods has also been increasing over the last century due to intensified land use, loss of forest cover, human encroachment onto flood plains and higher population densities in flood-prone areas [5].

Floods have both short and long-term impacts on communities [16, 92]. In the short term, floods lead to the loss of livestock and human life, increased risk of disease, reduced mobility, increased prices of goods, contaminated water, difficulty finding cooking material, damage to houses, and increased food insecurity [10]. Long-term effects of floods include fertility and soil loss on agricultural land, damage to infrastructure and housing, migration, and a devaluing of agricultural land [92].

There is extensive literature on how households cope with climate-related hazards. Household coping strategies used during droughts are diverse and highly location-specific [94]. However, the literature is in wide agreement that rural dwellers with diverse types of off-farm
incomes are most able to cope with drought stresses [12, 74, 92, 94, 95]. Major coping strategies used in semi-arid Africa include (from highest to lowest importance): food aid, indigenous fruit collection, livestock and poultry sale, casual labor, support from neighbors and family, credit, handicrafts, salaries, charcoal making, small businesses, and sale of land [12]. Flood-specific coping strategies include replanting crops immediately after the rains, temporary migration, and moving to high ground [92]. Specific coping strategies for rainfall variability, a relatively new phenomenon, have not received much attention in the literature. Future adaptation opportunities are discussed in Section Three.

Findings

**Impacts**

The Nyando District provided a unique opportunity to study the impact of climate-related hazards on farmers, as both a drought and a flood had recently hit the area. Lower and Middle Nyando experienced drought-like conditions in September and October 2009 when the short-rains season failed. Specific data on the intensity of the drought in this region is sparse, but food shortage was widespread in the Nyando region due to the water shortages [96].

During this time, farmers reported significant drops in farm productivity. In both Lower and Middle Nyando, farmers reported as much as a 96% decrease in farm productivity following the shortage of rains, leading to substantial food insecurity. This problem was only exacerbated by high staple food prices during this time. Maize prices per 90 kg bag in Kisumu were 50% higher than in average years [97]. Farmers in local markets also felt food price pressures, with maize prices during the drought more than doubling. Water collection during the drought period also put a large burden on women and children, as they had to travel long distances to find potable water.

In addition to this drought in the fall of 2009, the Lower Nyando region was also hit with a significant flood in March and April of 2010 that displaced 180 people and destroyed seven homes across the Nyando District [98]. Some farmers in the area argued that this flood was the worst since 1963 because, as one farmer explained, “everything was underwater, sometimes up to our chests.” According to local farmers, three people in the area died due to floodwaters and the rains forced a number of households to evacuate for up to three weeks.

During the flood, farmers reported a number of short-term impacts. Many farmers felt ‘stuck’ as they were forced inside and unable to perform normal household and farm chores. Finding dry fuel wood became a problem for many and cooking was significantly restricted because of the fuel wood shortage. Hunger during this time was also of major concern, with 60% of all households
in March and 70% in April reporting that they had experienced hunger during the height of the floodwaters. Fifty-five percent of households identified March and/or April 2010 as the most severe hunger period that they had experienced over the last twelve months. A hunger period, as defined by farmers, is a time when the household had severe difficulties obtaining enough food to feed all household members. Although March and April are often difficult months for hunger in this region regardless of weather conditions, the hunger experienced in March and April 2010 was exacerbated due to the rains.

In addition to the immediate impact felt by households during the flood, almost all farmers interviewed also noted extensive impacts of the flood on overall farm productivity the following season. Sixty percent of farmers surveyed identified heavy rains and floods as a major constraint to their seasonal farm productivity. Of those farmers who considered flooding a problem, 8% reported complete crop failure due to the exceptionally heavy rains. Of the two staple crops planted in the area, sorghum typically fared better than maize in recovering from the floods. Farmers believed sorghum’s deeper and denser root system prevented it from being uprooted. In addition to washing away entire fields of crops, the flood also caused stunted growth and reduced productivity of the crops that remained. Less than one month after harvest, one community group reported having run out of food due to low agricultural productivity after the floods.

Farmers reported that the flood had a significant impact on the long-term productivity of their land as well. In areas under standing water, much of the fertile topsoil was washed away and only hard-panned soil remains. Striga weed and other invasive plants were also reported to have increased in frequency following the heavy rains. The emergence of additional weeds following the floods has a long-term impact on these farms as many farmers cited weeds as a major farming constraint.

Surprisingly, farmers believe that unpredictable rainfall patterns had a more significant impact than the flood and drought on their farm productivity and well-being. Overall, farmers listed unpredictable weather as the largest constraint to long-term farm productivity.\(^4\) Weather-related variability is particularly detrimental to Lower Nyando farmers, with 92% of farmers listing it as a constraint to farm productivity. Qualitative discussions held with farmers confirmed that farmers believe unpredictable rainfall patterns are the leading cause for low farm productivity. Because of the shifting and unpredictable nature of rainfall patterns experienced by farmers over the last three to

\(^4\) Other constraints included: Access to capital, access to implements, access to inputs, family illness, labor, soil fertility, pests and diseases, and soil erosion
five years, traditional knowledge typically used to predict planting times is no longer useful, causing farmers to plant late. In addition, farmers report that weather forecasting in the area is often incorrect and unreliable.

Results from household surveys show that farmers’ farm productivity decreased by 60% and 39% in Lower and Middle Nyando respectively during the 2009-2010 growing season. Farmers attribute this decrease to a combination of the drought, flood and rain variability experienced in the past twelve months. Maize, the staple crop in the region, followed similar production trends due to rainfall fluctuations; see Table 4.3.

<table>
<thead>
<tr>
<th></th>
<th>2009-2010 Farm Productivity (Ksh)</th>
<th>Normal Year Farm Productivity (Ksh)</th>
<th>% D</th>
<th>Maize Production 2009-2010 (Kgs)</th>
<th>Normal Year Maize Production (Kgs)</th>
<th>% D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Nyando</td>
<td>8,200</td>
<td>20,500</td>
<td>- 60%</td>
<td>85</td>
<td>220</td>
<td>-61%</td>
</tr>
<tr>
<td>Middle Nyando</td>
<td>43,000</td>
<td>70,500</td>
<td>- 39%</td>
<td>900</td>
<td>1300</td>
<td>-30%</td>
</tr>
</tbody>
</table>

Table 4.3: Average farm productivity (measured in Kenyan Shillings) and maize production (in Kilograms) of farms during the 2009-2010 flood and drought year as compared to an average year with no major weather problems. N=116

As Table 4.3 shows, Middle Nyando farms were less affected by the 2009-2010 climatic shocks than their Lower Nyando counterparts. This difference is due in large part to the fact that Middle Nyando residents did not experience a flood in early 2010. In addition, Middle Nyando farms are, on average, far more productive due to higher average rainfall in the area. Farm productivity trends also impacted food security among households, as Middle Nyando residents reported experiencing hunger for an average of 2.2 months of the year, while Lower Nyando households experienced hunger for an average of 4.5 months. Farmers reported feeling more food insecure in 2009/2010 than in average years due to the weather-related crop failures.

**Findings - Coping Strategies**

To deal with the food shortages associated with the 2009-10 shocks and variability, a number of different coping strategies were used. Table 4.4 shows the primary coping strategies used by farmers during these times.
The most common coping strategies reported during periods of hunger was to reduce food consumption through restricting the size, diversity and number of meals taken each day. Those people that were involved in off-farm activities intensified their work in these areas and others engaged in casual farm labor. Selling of livestock during drought and flood periods was a popular coping strategy, with 55% of farmers selling livestock in 2009-10 specifically to deal with food shortage. One drawback of using livestock as an investment to be drawn on during times of need is that prices drop significantly during these periods. Prices reported during drought periods were between 50% and 75% of normal livestock prices, resulting in a significant decrease in returns when farmers were forced to sell during these periods of high supply and low demand.

Due to this scarcity of food, farmers were also forced to use many erosive coping strategies that have harmful long-term impacts on household productivity [99]. For example, during periods of hunger, farmers reported being forced to sell oxen reserved for plowing, leading to lower farm productivity the following season as people then had to plow by hand. Sixty-six percent of farmers reported consuming seeds reserved for planting. This consumption had repercussions, as many farmers were then unable to plant hybrid seeds the following season due to constraints in capital and the depletion of their personal seed stores. In Middle Nyando, limited capital following the drought also restricted farmers’ ability to purchase fertilizer and other chemical inputs regularly used. Some Middle Nyando farmers also reported being forced to lease their farms for two years to wealthy farmers in the area in order to feed their families. This coping mechanism is especially detrimental as it prevents farmers from accessing their main source of livelihood, their land, for the next two years. According to some farmers, engaging in casual labor also represents an erosive coping strategy as it delayed the planting in their own farms. Overall, Middle Nyando farmers used fewer negative coping strategies than their Lower Nyando counterparts, likely due to the lower intensity of the hunger period experienced in the Middle Nyando region.

Although not necessary during the 2009-2010 drought period, farmers have also been forced to migrate temporarily to the Rift Valley, an area of higher productivity, in search of work. Many of

<table>
<thead>
<tr>
<th>All #s in %</th>
<th>Lower Nyando</th>
<th>Middle Nyando</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 4.4: Proportion of farmers using coping strategies to deal with flood and drought in 2009/2010. All numbers are in percent. N=116
the elder farmers in the area noted that they were particularly disadvantaged during the last serious drought in 2003, as their physical health prevented them from being able to partake in labor migration.

Discussion

Currently, the communities I interviewed are not able to cope with climate-related hazards in a sustainable way, as was clear through the number of erosive coping strategies used during periods of hunger. Food insecurity, particularly for Lower Nyando, is a large problem that is substantially exacerbated by weather-related events. The food price spikes during the drought were especially difficult for households. Although the Kisumu maize market may have been partially influenced by the global price spikes of 2008-2009, the local markets are largely insulated from global fluctuations as trade is almost entirely confined to the immediate region. Therefore, the local price spikes observed can be attributed to the drought conditions in the area. This is concerning in light of the predicted increase in frequency of droughts in the area, as this will likely lead to more frequent spikes in staple food prices in the area [100].

Much of the literature has focused on the long-term effects climate change will have on agricultural production, looking at trends in temperature, precipitation, and changes in season length [6]. However, it is clear that the short-term effects of seasonal weather variability have a strikingly large impact on rain-fed subsistence farmers. This finding supports the conclusions of Corbera et al., that climate research needs to take more seriously the short-term effects of climate variability on farmers’ lives [101].

Improving localized weather forecasting can help farmers deal with short-term weather variations. But currently farmers interviewed do not trust weather forecasting, so any programs to encourage reliance on such forecasts will take time for farmers to adopt. It is possible to change these attitudes toward weather forecasting. A study in Zimbabwe showed that farmers involved in participatory workshops on the uses of weather forecasting began using and benefiting from these local predictions [102]. There has been progress in the area of localized weather forecasting across eastern and southern Africa, yet there is substantial room for expanding these local forecasting networks [103]. Better flood and drought preparation will also be necessary, as most communities were not taking any precautionary measures to deal with future floods or droughts. A discussion of potential adaptation strategies to increase farmer resilience in the face of these climate exposures is explored in Section Three. By improving the adaptation of farmers to these climate-related hazards, it
is hoped that farmers will no longer be forced to rely on their current unsustainable coping strategies.

Section Three: Improving Resilience to Climate-Related Hazards Through Adaptation Measures

In this section, I continue with the third section of the Turner et al. (2003) framework by discussing potential adaptation strategies to improve future resilience of farmers to climate-related hazards. I first examine what suggestions have been put forth by the scholarship on the topic and then compare these findings with the suggestions farmers gave for future adaptation measures.

Literature Review

Much of the literature agrees that an effective way to reduce farmers’ vulnerability to climate-related hazards is to improve the general well-being of rural households [12, 74, 92, 95]. To reduce vulnerability to climate hazards, many encourage the diversification of rural livelihoods through increasing off-farm income opportunities, expanding crop varieties and improving access to markets [10]. Better agricultural training, transport, communication systems, community organizing, and improved crop varieties can also help farmers reduce their vulnerability to future climate-related hazards [74, 92]. Improving vegetation cover and water filtration of soils through planting trees can also help with the long-term effects of floods and droughts, as tree roots can help reduce soil erosion and runoff, while improving the water-holding capacity of soils [15]. In addition, improved forecasting of local weather can also facilitate adaptation [13]. Conway (2009) stresses that any adaptation measures undertaken must be practical and beneficial in the face of future climate variability while also being locally driven [10]. He also argues for learning from past climate stresses to help local communities be better prepared for future shocks.

In addition to general adaptation strategies, the literature also suggests adaptation measures for specific types of climate-related hazards [104]. To mitigate vulnerability of farmers’ well-being to changing rainfall patterns, farmers could adapt by changing the planting dates of their crops, planting different crops during the short-rains period and changing the varieties of crops planted [13, 70]. However, upon review Howden et al. suggests that such changes in agriculture techniques can only help mitigate the effects of moderate climate variability, more extreme forms of climate change will require additional adaptation measures [104].
Specific adaptation strategies for future droughts include improved water storage facilities and short-term migration [74]. Long-term adaptations to floods include improving water infrastructure such as dams, levees and water storage reservoirs and environmental improvements such as extending wetlands, improving water filtration of soil, and reducing agricultural runoff. In addition, adaptation can be improved through flood forecasting, land-use planning, emergency committees and preparedness education among communities [74].

The barriers to the adoption of these adaptation measures include poverty, lack of access to credit, and lack of information [82]. Studies find that farmers with more agricultural knowledge and skills, better access to credit, more secure property rights, higher levels of wealth, access to off-farm employment and higher educational levels all are more likely to invest in adaptation measures [82, 105].

**Findings**

In Middle and Lower Nyando, few new adaptation opportunities exist for farmers to deal with the increasingly unpredictable rains and droughts. As one farmer explained, “we are reliant on the rains from God, and there is nothing we can do to change these patterns.” Many farmers had dug water ponds to store excess rainwater, but this technique has only occurred on a very small scale. Existing coping strategies to deal with floods include building trenches and reservoirs to divert and store excess water. Some farmers reported creating such trenches but due to the labor requirements, people only built trenches to protect their homes. Many farmers would like to expand these trench systems to better cope with future floods. One community group also constructed reservoirs and canals to divert and hold the excess water, but due to the small scale of the project, these pools broke down in the heavy rains. Some farmers are hopeful that small-scale irrigation projects could help in the future but due to capital constraints they are unable to purchase irrigation equipment. In addition to water storage ponds, other potential adaptation strategies discussed included the use of large containers to store rainwater, but again, the lack of capital prevented most households from using this technique. Farmers in Middle Nyando are also talking about planting sorghum, a crop that is more drought-resistant than maize. However, farmers explain that the downside to planting sorghum is that it is not as palatable or productive as maize.

By far, the most effective long-term adaptation strategy is to diversify one’s income to include off-farm activities according to all households interviewed. Farmers who engaged substantially in off-farm activities, such as wage-earning jobs, owning small shops, or selling
livestock, report being better able to cope with climate-related hazards than their farming-neighbors. Farmers with higher average farm productivity also report fairing better during rainfall variations as they had more stores to draw on when current productions were low.

Farmers were more hesitant to diversify the crops they grow in order to adapt to the changes in current weather patterns. They felt that the crops they were growing ‘should’ work in the region because this was what their parents and grandparents had used. When I presented my research findings to the farmers, I aggregated results that showed that farmers’ reported their maize crops failing four times more frequently than their sorghum crops. This finding led into a discussion about crop diversity and most farmers were interested in changing their cropping practices to better suit the current, drier, weather conditions. They explained that prior to this discussion, they had not considered diversifying crop varieties as an option to deal with weather variation. From the discussion, farmers concluded that by planting more native species such as sorghum and millet they might be better able to deal with the current weather conditions they face today. Many farmers are trying a new mix of crops in the upcoming season.

To prepare for future floods, farmers plan on planting additional trees and other shrubs around their farm and homesteads to reduce soil erosion and slow water velocity traveling down hills. Trees are helpful because, according to one farmer, “it keeps the soil here.” Even farmers who had not been involved in an agroforestry development project cited the potential uses of trees to reduce their vulnerability to floods. Farmers were also interested in trees to help them deal with droughts, as they found that selling tree crops, like fuel wood and fruit, during times when other crops had failed provided them with additional income to purchase other food.
Discussion

<table>
<thead>
<tr>
<th>General Adaptation Strategies</th>
<th>Rainfall Variability</th>
<th>Droughts</th>
<th>Floods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase off-farm income</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Improve agricultural knowledge</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Weather forecasting</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Improve transportation and access to markets</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Improved tree and vegetation cover on agricultural land</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Diversify crop species</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Specific Adaptation Strategies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water storage facilities</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dams, levees, trenches</td>
<td>×</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Community emergency committees</td>
<td>–</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Drought-resistant crops</td>
<td>–</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Small-scale irrigation</td>
<td>✓</td>
<td>✓</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 4.5: A matrix of coping and adaptation strategies mentioned in the literature and by farmers and their projected impact in reducing farmers’ vulnerability to rainfall variability, droughts and floods. Assessment of the effectiveness of each strategy was determined based on qualitative discussions with farmers who had tried these practices as well as from the literature on adaptation strategies. ✓ refers to a strategy that farmers and the literature both found to be effective in reducing vulnerability; – is a strategy that has no effect on reducing vulnerability under the specific climate hazard; × is a strategy that has negative effects on farmers under the specific climate hazard.

A number of the adaptation measures suggested by farmers to reduce their vulnerability to climate-related hazards are echoed in the literature. These adaptation and coping strategies are summarized in Table 4.5. See Appendix 4.1 for justifications of the matrix. From this matrix, general strategies that improve farmers’ well-being appear to be effective in dealing with all three major climate-related hazards. This finding agrees with much of the adaptation literature’s conclusions that general adaptation measures will be effective in reducing vulnerability to climate-related hazards [10, 87].

It was interesting that farmers had not considered diversifying their crop species to better fit the current weather conditions. Much of the literature suggests diversifying crops as a general adaptation technique to take advantage of different crop’s ability to thrive under different weather conditions [104]. The fact that farmers had not even considered this option until it was brought up during the research process shows the need to provide information to farmers about potential strategies that can help them better adapt to climate change. Farmers also expressed an interest in having more detailed information on scientific predictions of future climate change in order to be better informed about how their farming practices will need to change.
In the Nyando region, some specific adaptation strategies appear to be worthwhile investments from the perspectives of both farmers and expert reviews. Projects should explore the expansion of water storage ponds for drought and flood protection as well as small-scale drip irrigation opportunities in the area. Social safety nets through community response teams and preparedness education could substantially benefit rural dwellers as climatic hazards increase. Currently, no such systems are in place.

However, other specific adaptation strategies, particularly dams, levees and trenches and drought-resistant crops may actually increase farmers’ vulnerability under certain climate-related hazards. Large-scale flood infrastructure is likely to be too costly to maintain for most rural areas and can have negative environmental consequences downstream [74]. Therefore, these strategies should be avoided. Farmers also complained that drought-resistant crops decreased their overall yield when there were normal or heavy rains. With the uncertainties in climate change projections, it is important to focus on adaptation strategies that can help ensure farmers’ well-being under a variety of different forms of climate-related hazards. As climate projections improve, more specific adaptations can be encouraged [10].

Conclusions

Farmers in the Lower and Middle Nyando region are already feeling the effects of climate change. Exposures to floods, droughts and rainfall variability are only predicted to get worse as the impacts of climate change increase. The consequences of these hazards on farmer well-being are severe, inducing intense episodes of food insecurity, which force farmers to engage in erosive and unsustainable coping strategies. The literature and my findings agree that substantial improvements in the resilience of rural farmers is needed to address the current and increasing vulnerabilities of subsistence farmers in Eastern Africa.

I argue that the most effective way to reduce vulnerability of farmers is through general adaptation strategies that focus on improving overall farmer well-being. A number of specific adaptive strategies, such as water storage and small-scale irrigation, also appear to be viable options. However other specific adaptation strategies were found to have negative consequences under certain climate-related hazards. This finding highlights the need to do place-based studies of adaptive strategies to assess which specific projects will be most effective at reducing farmer vulnerability under a wide variation of climate hazards. Despite the promise of some specific
adaptation measures, farmers emphasized their desire to remain autonomous in deciding what type of specific adaptation measures they choose to employ. They are looking for support in improving their general well-being so as to be in a better position to use their own resources to adapt to future changes.

Although it is important to recognize the autonomy of farmers in their adaptation choices, it was also clear from discussion with farmers that they will need and are interested in receiving information and advice on potential adaptation strategies. This distinction between outside organizations’ role as an advisor on adaptation options and an implementer of specific strategies is somewhat nuanced, but will be an important one to distinguish to ensure farmers buy in to future adaptation strategies. Adger et al. (2005) highlight the need to facilitate adaptation strategies among individuals and not solely rely on individual autonomy to make the most effective decision [106]. Future research is needed to find effective advising strategies that can help farmers access information on, and capital to invest in, specific adaptation strategies. In the following chapter, I examine whether, and, if so, how agroforestry practices can contribute to improving farmers’ well-being in the face of climate-related hazards.
Chapter Five: The Role of Agroforestry in Reducing Farmers’ Vulnerability to Climate-Related Hazards

In Chapter Three, I explored how both farmers and the literature define a successful life and found that farmers are most interested in improvements in food security, income and farm productivity. Farmers are also interested in the environmental sustainability of their farming practices. In Chapter Four, I found that exposure to climate-related hazards increase food insecurity and force farmers to engage in unsustainable coping strategies that have long-term negative impacts on farmers’ well-being. I concluded that the most effective way to mitigate the vulnerability of farmers to climate-related hazards is through general strategies that improve their farm productivity and incomes, though some specific adaptive strategies may also have a role to play.

This chapter examines whether, and, if so, how, agroforestry practices can help farmers reduce their vulnerability to climate-related hazards. There are a multitude of potential approaches that can improve farmer well-being; however, scholars have recently become particularly interested in agroforestry techniques because of their joint role in climate change mitigation through carbon sequestration and supporting farmers’ adaptation to these changes [22]. Studies have shown that agroforestry can improve farmer well-being and environmental health [28]. However, many of these studies have either been qualitative or were field experiments led by scientists [107]. Most studies focus only on the long-term time horizon of agroforestry projects of four or more years. In this chapter I combine both qualitative and quantitative analyses to examine how farmer-led agroforestry development projects can improve farmer resilience to climate change in the first two to four years of project implementation. My conclusions support the literature’s assertion that agroforestry can be an effective tool to help farmers reduce their vulnerability to climate change [2].

Agroforestry, as introduced in Chapter One, is the intentional use of trees in the cropping system to improve farm productivity. There are a number of different forms of agroforestry techniques. This analysis focuses mostly on the intercropping of trees among food crops to increase farm productivity and on tree planting on degraded lands to reduce soil erosion and provide a source of fuel wood, fruit and timber. Tree intercropping techniques involve interspersing nitrogen-fixing trees among crop rows and incorporating the nitrogen-rich leaf matter into the soil to increase soil fertility, see Figure A1.1 in Appendix 1.1 for images of agroforestry intercropping techniques.
I begin this chapter by reviewing farmer perceptions of agroforestry techniques. Negative perceptions of agroforestry techniques can act as a major barrier to the uptake of these practices. Then, I explore the direct role that agroforestry plays in helping farmers improve their well-being through improving their supplies of fuel wood and reducing soil erosion rates. I complete my analysis by examining how farmers’ involvement in agroforestry development projects affects general farmer well-being through changes in household farm productivity, wealth and food security. I find that agroforestry does improve farmers’ well-being, and thus reduces vulnerability to climate-related hazards, through small increases in household wealth and farm productivity. My findings on agroforestry’s impact on food security vary across sub-locations. Agroforestry involvement also provides some specific coping strategies to climate-related hazards by providing fruit, accessible fuel wood and reducing soil erosion in times of floods and droughts. When interpreting my results, it is important to remember that the agroforestry project I used for my evaluation has only been in operation for two to four years and thus the long-term effects of agroforestry involvement are not likely to be captured in my analysis.

**Section One: Farmer Perceptions and Uptake of Agroforestry**

Before exploring how agroforestry impacts farmers’ lives, it is important to first understand how local farmers view these practices and understand their effects. The literature has found that the adoption and diffusion of agroforestry practices has been a major problem in the agroforestry development field [108, 109]. For example, dissemination of agroforestry techniques beyond project-sites rarely occurs [23]. Development practitioners blame the intensive knowledge needed and the complexity of the techniques for the slow adoption of agroforestry, as well as the lack of understanding of potential benefits among the target population [108]. It is necessary to continue researching the implementation strategies of agroforestry development projects in order to better understand how uptake among farmers can be encouraged.

Below are some general findings on the perceptions, uptake and benefits of agroforestry from the perspective of local farmers. The views presented here influence analyses later in this chapter because they help to explain agroforestry adoption rates, intensity of agroforestry techniques used and farmer commitment to tree care. These factors are all important aspects to consider in examining the impacts of any agroforestry project.
**Findings**

*Initial Perceptions of Agroforestry:* Initially, farmers were very hesitant to use the intensive agroforestry practice of intercropping trees. Only a few farmers chose to intercrop their trees and maize as suggested by ICRAF staff. These farmers were laughed at by their neighbors and told they were wasting their time and land. Instead, most farmers engaged in less-intensive agroforestry techniques by planting trees to restore degraded land and to serve as boundary markers. Trees planted in this way can help provide fuel wood, timber and fruit, but such practices have no impact on farm productivity as the trees are not interspersed with the crops. When ICRAF staff first suggested planting trees in farmers’ fields, farmers thought ICRAF was trying to steal their land and many community groups refused to work with the project.

*Uptake of agroforestry:* Farmers involved in tree intercropping said it took three years before neighbors began realizing the benefits that the trees were providing to their maize yields and began asking them how to use trees effectively on their farms. Other farmers interviewed agree that in order to convince them that intercropping trees on their land is effective, they would have to see the technique in practice first. Farmers are very risk-averse when dealing with farming practices because, as one farmer explained, “this field, it is our livelihood.” Community groups that had a better understanding of potential tree benefits were more willing to take up intensive agroforestry practices and their members took better care of their tree seedlings.

*Benefits:* Farmers defined the most important benefit of agroforestry to be the income opportunities it provided through the sale of fruit, timber and fuel wood. Next, farmers cited soil erosion control and the provision of fuel wood as other major benefits of agroforestry techniques. Other notable uses included improving farm productivity, shade, windbreak, fruit and traditional medicine resources. These findings on the benefits were consistent across focus group discussions and individual surveys. All farmers that have successful seedlings on their land plan to continue to use agroforestry techniques and are very interested in growing more seedlings.

Farmers also understood the importance of trees from a cultural perspective, as previous generations highly valued trees in the cropping system and worked to maintain a healthy vegetation cover of indigenous trees over the farming landscape. Farmers explained that forty years ago, the land had three to four times the tree coverage it does today. In the last twenty years, growing population pressures forced people to cut trees due to hunger and poverty. Many people cited the high deforestation rates as a key cause of the current environmental degradation, soil erosion and low farm productivity in the area.
**Constraints:** In addition to the benefits seen by farmers in agroforestry projects, there were also a number of constraints that inhibited their uptake of agroforestry practices. Understanding these constraints is important to better prepare future agroforestry development projects and these findings are used extensively in forming my recommendations at the end of this paper.

The largest drawback to tree planting was the wait required before benefits could be received. As one farmer explained, “you have to be patient, very patient with trees.” In addition, many farmers complain of lack of knowledge to deal with problems that arise with their seedlings. During droughts, tree seedlings suffered substantially, with farmers reporting drought conditions as a key cause for seedling failure.

My quantitative analysis suggests that poverty is a constraint to agroforestry uptake, and that wealthier farmers were more effective at capturing the benefits of agroforestry techniques. For farmers in the highest quartile of household income, their seedlings had 10% higher survival rates among their seedlings when compared with the lowest quartile of household incomes, (p=.194). From discussions with farmers, this difference is due to the labor and capital burden of properly caring for tree seedlings in their first two years. Farmers spent an average of six hours per week caring for their seedlings for the first two years. After two years, trees need substantially less care, as the trees are nearing maturity. For poor households, tree care duties were ignored during times of hunger or drought, when household survival was of utmost importance. Wealthier farmers often had more labor available and did not have to be as concerned with mere survival, so a larger priority was given to tree health. A more in-depth understanding of tree benefits helps improve uptake of practices and care for seedlings, pointing to the need for better introductory education on agroforestry impacts and field visits to view successful agroforestry practices.

**Discussion**

It appears the most effective way to improve uptake of intensive agroforestry practices is for farmers to see the effects of agroforestry techniques on other farms in the area. These findings are consistent with literature on agroforestry adoption, which finds that adoption diffusion occurs more quickly at the later stages of agroforestry practices after benefits have been demonstrated [108]. The risk aversion noted among many of the farmers is also quite consistent with other evaluations on agroforestry adoption [110].

Farmers’ views of the variety of benefits of agroforestry are also similar to those found in other field studies, but farmers in this study put more of an emphasis on the benefits of soil erosion
control. This awareness is likely due to the education provided by ICRAF, as soil conservation was a major focus of the projects. Other literature found farmers ranking soil erosion lower which might reflect the different training provided in these projects [44]. The fact that farmers are interested in continuing their current agroforestry techniques and expanding the areas on which they plant trees suggests that farmers have seen tangible benefits in these practices, even after only two to four years of involvement.

The constraints listed by farmers are also consistent with other literature, although many studies on agroforestry adoption note land tenure to be a limiting factor in adoption [111]. Land tenure did not come up as a problem among farmers interviewed, although this finding may be because land ownership was relatively high in the area. Poverty is also frequently cited as a constraint to agroforestry uptake, agreeing with my findings that seedling success was higher among wealthier farmers [112, 113]. It may help agroforestry uptake if projects provided some form of incentives to farmers during this initial two-year window of agroforestry involvement, as farmers are investing substantial amounts of time into seedling care while getting no immediate returns for their work. The fact that farmers are willing to put in this initial work shows that farmers do highly value the potential benefits trees will provide them in the long-run. I return to this finding in my recommendations section of Chapter Six.

It is important to consider farmer perceptions and their uptake of agroforestry when considering the impacts that agroforestry projects have on farmers’ well-being. It is likely that if farmers had engaged in more intensive agroforestry practices, or if they had been more successful in maintaining healthy seedlings, there may have been larger changes in farm productivity, household wealth and food security. However, one of the benefits of this analysis is that it examines agroforestry in the context in which farmers are practicing it everyday. Scientist-led studies of agroforestry techniques find that agroforestry involvement improves farm productivity by a much larger magnitude than shown in my results because of higher seedling survival rate and more intensive agroforestry practices used [114]. However, it is not scientists and scholars who implement agroforestry projects. Farmers do. Therefore, as I explore in my recommendations, farmers’ perceptions of agroforestry projects contribute substantially to the overall success of the project. With the perspective of the farmers in mind, I examine how involvement in agroforestry projects affects farmer well-being.
Section Two: Direct Agroforestry Impacts

Once farmers choose to engage substantially in agroforestry practices, these techniques provide direct benefits for them through the time saved on fuel wood collection and through reducing soil erosion. In this section, I show that agroforestry involvement reduces time spent collecting fuel wood by an average of three hours per week and reduces soil erosion in agricultural fields. These results have important implications, as the problems of fuel wood scarcity and soil erosion are increasing in sub-Saharan Africa.

Fuel Wood

Fuel wood is becoming increasingly scarce in much of rural Africa as deforestation continues. Agroforestry is an obvious tool to help with fuel wood scarcity, as pruned branches can be used as a sustainable source of fuel wood. It is expected that those farmers with higher agroforestry involvement will spend less time on fuel wood collection per week, as fuel wood is more readily available on their land. First, I review the literature on the current demand for fuel wood in Africa and agroforestry’s role in fuel wood provision. I then present my qualitative and quantitative findings, showing the increasing demand for wood in highly deforested areas and agroforestry’s ability to reduce time spent collecting fuel wood while increasing the sustainability of fuel wood collection.

Literature Review

2.5 billion people depend on biomass fuels for cooking around the world [115]. In Africa, the demand for fuel wood is expected to continue to increase until at least 2030, and many regions are already facing severe wood shortages due to increasing population pressures [115, 116]. Because of the shortage, people are often forced to harvest wood in unsustainable ways [115].

In Kenya, 71% of all energy consumption comes from biomass [117], and according to one analysis, 90% of households of western Kenya were not self-sufficient with fuel wood supplies [36]. Due to scarcity, Haile et al argue that rural households spend a large portion of their day looking for fuel wood instead of engaging in productive agriculture work [118]. These findings show the important role that fuel wood collection plays in everyday life for rural African families, and highlights the need to find a sustainable approach to fuel wood harvest.

Agroforestry practices have been shown to provide ample fuel wood supplies for rural households. In Rwanda, one hectare of farmland under intense agroforestry can produce 140% of
the fuel wood required for a six-person family [26]. Using low-intensity agroforestry in Tanzania, fewer than two hectares were required to provide enough fuel wood for a family of six [26]. All of the studies reviewed on fuel wood scarcity in Africa suggested agroforestry as a solution to current unsustainable fuel wood extraction practices [26, 115-117].

Findings

On average, households in my study report spending 6.4 hours on fuel wood collection per week. Most farmers (73%) report collecting fuel wood from their own land, with community land being the second most frequented location for fuel wood collection. In addition, 18% of farmers are forced to purchase fuel wood from the local markets or neighbors.

In the Lower Nyando region, where the landscape is almost entirely deforested, households spend an average of nine hours each week on fuel wood collection. A larger proportion of farmers in this area are forced to purchase fuel wood, with 30% of farmers buying fuel wood on a weekly basis. Lower Nyando residents also put higher pressure on community land forest cover, with 39% of farmers deriving at least some wood from community land. In contrast, in Middle Nyando where tree cover is higher, fuel wood collection time per week is substantially lower, at just under 5.5 hours per week and only 6% of the farmers purchase wood.

From individual discussions with farmers, fuel wood collection has become increasingly more difficult over time as tree cover continues to decrease. Some farmers are now forced to walk over twenty kilometers to purchase fuel wood in neighboring districts. Women in low tree-density areas are also beginning to face threats from their neighbors in a struggle over this limited resource.

Considering that it is the women’s job to collect fuel wood, it is interesting to note that in group discussions, men ranked the trees’ ability to provide fuel wood higher in importance than women did. During the debriefing sessions that followed, men explained that they were concerned with the amount of time women were forced to spend on fuel wood collection in light of their other farm and household duties. The women, on the other hand, saw fuel wood collection as an inevitable part of their daily chores. The task of fuel wood collection is put almost entirely on women and female children, who report feeling overburdened with household and farm duties.

Agroforestry’s Impacts: My research shows that agroforestry involvement leads to substantial reductions in the time that households use to collect fuel wood. According to farmers I surveyed, fuel wood was the second most commonly cited use of trees on the farm. Households that have been involved in agroforestry for four years report spending on average three hours less time
collecting fuel wood per week than those farmers who have little or no agroforestry exposure. These farmers are now able to rely much more on fuel wood from their own land rather than from community areas. Women with mature trees on their land feel that they now have access to a safer and more stable supply of fuel wood. These women report devoting more time to income-generating activities and farm care now that fuel wood stocks are nearby.

There is also a negative correlation between the number of trees on one’s land and average weekly fuel wood collection time. Households with more mature trees on their land spend less time collecting fuel wood each week. My quantitative analysis shows that as agroforestry involvement increases, time spent collecting fuel wood decreases. A log-log transformation of the variables shows a significant negative relationship (corr= -0.160, p=0.007), see Figure 5.1. See Appendix 5.2 for extensive analysis. This analysis was replicated using different measures of agroforestry involvement and similar trends were observed.

![Figure 5.1](image)

**Figure 5.1:** A log-log transformation of tree biomass per household and household fuel wood collection time per week with a standard line of best fit. Tree biomass acts as a proxy for agroforestry involvement in this analysis.

**Discussion**

From these results, it is clear that fuel wood collection is an integral part of farmers’ lives and that the collection of fuel wood is becoming more difficult as tree cover decreases. Farmers are becoming increasingly reliant on personal fuel wood supplies as community stocks are dwindling due to overuse. These findings highlight the need to improve tree cover on local farms to provide wood in an increasingly fuel-scarce environment.
Farmers can reduce their fuel wood collection times by increasing the number of mature trees on their land. Farmers involved in agroforestry are also able to harvest fuel wood at a more sustainable rate while maintaining the health of the trees by using only dead or excess branches. This may improve general household well-being by saving time of overburdened women. Men interviewed feel that women are forced to spend too much time on fuel wood collection, which negatively impacts the household’s ability to accomplish all home and field chores.

There is also an opportunity in low tree-density areas to increase off-farm incomes of women through local fuel wood sales. There is a substantial demand for purchased fuel wood in these areas, yet only two farmers reported having enough excess fuel wood on their land to sell fuel wood at the market. As many rural areas struggle to find sustainable, small-scale opportunities for improving incomes, fuel wood sales may provide an excellent option for those farmers engaged in agroforestry practices. Due to the fuel wood scarcity in the area, farmers may also be interested in fuel-efficient stoves that have been shown to use one quarter of the wood required in a normal stove, however currently there is much skepticism of these new stoves in this area [119].

**Soil Erosion**

The scientific community frequently cites soil erosion as a major problem for the long-term sustainability of agricultural productivity [38]. Soil erosion is the loss of soil from an agricultural field, typically caused by wind or rain [120]. See Figures A1.3 and A1.4 in Appendix 1.1 for images of soil erosion in the research site. The use of trees in the cropping system has been shown to reduce soil erosion through the tree’s extensive perennial root systems [24]. In this section, I review current research on soil erosion and agroforestry and then present my findings that show agroforestry’s role in reducing soil erosion.

**Literature Review**

Soil can be considered a non-renewable resource as soil takes centuries to form, yet around the world, agricultural lands are losing over 75 billion tons of soil each year [38, 121]. For Kenya, it is estimated that soil erosion costs the country $390 million, or 3.8% of GDP each year, through lost agricultural productivity and negative aquatic impacts [38]. The Nyando River Basin of western Kenya is considered to be a soil erosion hotspot, with some of the most severe erosion on the continent [38].
Soil erosion reduces farm yields from anywhere between 20% to 80% when compared with yields on non-degraded soils [122-124]. Planting on degraded soils also doubles the likelihood of crop failure [123]. Soil erosion causes reduced yields because of nutrient loss, reduced water retention and infiltration, reduced soil organic matter and restricting plants’ root depth [24, 122, 123]. Soil erosion is also expected to increase with climate change, as rainfall is projected to fall with increasing intensities, and the intensity of rainfall is correlated with rate of soil erosion loss [125, 126]. One study on farmer perceptions of soil erosion in Kenya found that farmers are concerned with this issue, though they generally underestimate the importance of soil conservation, as the negative effects manifest slowly over time [44].

Agroforestry has been shown to reduce soil erosion by providing a perennial root system that holds together soil particles [24, 122, 123, 127, 128]. However, the success of agroforestry in reducing soil erosion depends in large part on the type and intensity of the agroforestry practice [127].

Findings

50% of farmers surveyed consider soil erosion to be a constraint to the long-term farm productivity of their land. However, farmers identified soil erosion as the least important factor in a ranking of nine farm productivity constraints. Although farmers do not identify soil erosion as a major problem, individuals have made efforts to reduce soil erosion using traditional practices, such as planting aloe vera along field slopes, even prior to the involvement of NGOs that suggested soil conservation techniques. One community group that was involved in soil conservation activities under an NGO project in 2006-2008 continues to plant trees on community land today, even after project support ceased.

Farmers attributed soil erosion to heavy rains and a decrease in vegetation cover on the land. Soil erosion was particularly detrimental to people affected by the 2010 floods in Lower Nyando, with many farmers complaining of decreased soil fertility due to the intense soil erosion during these heavy rains.

Farmers consider tree planting to be more effective than traditional methods of shrub planting as a measure to prevent soil erosion. Furthermore, farmers identified that one of the most beneficial uses of trees is the protection they provide against soil erosion. These opinions might be

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5 This list of constraints included (from most significant to least significant): Unpredictable weather, access to capital, access to implements, access to inputs, family illness, labor, soil fertility, pests and diseases, and soil erosion.
somewhat biased due to the training provided by ICRAF staff that focused on the capabilities of trees to prevent soil erosion.

My field observations support farmers’ claims that increased tree density reduces soil erosion. As can be seen in Figure 5.2, the data show a downward trend when the log of agroforestry involvement is plotted against a scale of soil erosion observed, showing that, on average, farmers with higher tree biomass per acre experience less soil erosion (Corr Coef=-0.28; p<.0001). See Appendix 5.2 for detailed analysis.

Figure 5.2: Soil erosion plotted against the log transformation of tree biomass per acre. Corr Coef= -.28; p<0.0001

Upon a detailed analysis by sub-location, I found that farms that have been involved in agroforestry practices for four years exhibited much lower soil erosion than similar farms in the area that have not been engaged in agroforestry practices (p<.0001). There was also significantly less soil erosion in Middle Nyando when compared to Lower Nyando (p<.01). This supports the above hypothesis, as the average tree density is much higher in Middle Nyando.

Discussion

Although farmers do not consider soil erosion to be the most pressing problem to their farm productivity, communities have invested in soil conservation measures. This investment suggests that soil erosion is a problem severe enough to warrant the labor and capital costs associated with these prevention activities. This finding is similar to those presented by Okoba [44], who shows that farmers see soil erosion as a problem, but not a major priority.

My findings also agree with predictions that soil erosion will increase with climate change [126]. The severe floods in 2010 had serious impacts on soil erosion, leaving some fields completely
stripped of topsoil. Flood events are only predicted to increase in severity and frequency [79]. These findings have large implications for the importance of future soil conservation measures, as there was a clear decline in soil fertility and farm productivity after the floods and the ensuing soil loss.

One question that the distribution of this data brings up is the high frequency of observations of low soil erosion and low tree biomass. From the data available, it is impossible to draw a causal relationship between soil erosion and agroforestry involvement; nevertheless, both the literature and qualitative and quantitative data presented here support such a relationship. Future studies will need to include a larger data set to test whether these results can be verified.

**Section Three: Indirect Agroforestry Impacts**

Agroforestry has been shown to provide substantial improvements to farmer’s well-being through improving farm productivity, household income and food security. In this section, I report on three detailed analyses of agroforestry’s role in improving farmers’ well-being. My results support the argument that agroforestry improves farm productivity and household income, within the two- to four-year time period assessed, while providing mixed results on food security impacts. These conclusions suggest agroforestry practices as a means to reduce farmer vulnerability to climate-related hazards, as farmers are interested in ways to improve farm productivity and incomes.

Ideally, this study would have taken place over an extended period of time to capture long-term changes in individual households. However, due to time and data constraints, this was not possible. Therefore, all quantitative analyses presented here compare farmers involved in agroforestry practices for two to four years with a control group that has never engaged in agroforestry practices, controlling for basic household parameters. For detailed description of methods used, see *Chapter Two*. Despite these limitations, the quantitative analysis undertaken is consistent with all qualitative findings and thus provides an additional robustness to the discussions that follow.

**Farm Productivity**

Advocates of agroforestry argue that agroforestry practices can increase farm yields. However, there are limited studies testing this hypothesis with agroforestry development projects outside of scientist-led field studies [28]. Scientist-led field studies do not accurately replicate
agroforestry practices among rural farmers because the trees are cared for and overseen by scientists, not farmers. This section examines if involvement in a farmer-led agroforestry development project improves subsistence farmers’ farm productivity. First, I present a literature review that examines the current findings on the agroforestry’s role in improving farm productivity. Through my analysis I find that involvement in agroforestry development projects does marginally improve farm productivity.

**Literature Review**

Practitioners and researchers have advocated agroforestry practices as an excellent way to increase crop yields for small farmers without access to or capital to purchase inorganic fertilizer [2, 24, 47, 90, 114, 129]. Trees have the potential to improve soil fertility, and thus crop yields, in a number of ways. Most commonly cited is the ability of leguminous trees to increase crop productivity by providing nitrogen, a limited plant-nutrient [26, 130-132]. A literature review of 94 peer reviewed journal articles on the impacts of nitrogen-fixing trees on crop productivity in southern Africa found that intercropping agroforestry techniques doubled maize productivity when compared with unfertilized fields [132]. The potential for agroforestry practices to improve crop productivity was even more substantial in low agriculture potential sites [132]. Agroforestry practices can also improve soil fertility by increasing organic soil carbon content, bringing more nutrients to the soil surface, improving nutrient cycle efficiency, changing the physical characteristics of the soil and increasing soil moisture [26, 114, 123].

However, some literature debates the capacity of agroforestry practices to improve crop productivity in farmer-led studies. Winterbottom notes that there have been extensive case studies of increased fertility of soils through agroforestry practices, but less extensive evidence for increased crop yields [26]. Three case studies in western Kenya found that agroforestry techniques used in farmer-run projects did not increase farm productivity, regardless of the type of agroforestry practice used [107, 112, 133].

These results do not entirely contradict Sileshi’s meta-analysis of agroforestry case studies, as Seleshi notes a wide variability of yields in agroforestry trials [132]. Differences seen across this literature review may be due to the circumstances of those who implement the agroforestry projects, as tree survival was often lower for farmer-run projects as compared to scientist-led studies [133]. There is clearly a distinction between agroforestry practices implemented by scientists and by rural
farmers. The feasibility of improving farm yields in farmer-led programs should continue to be explored [28].

**Findings Qualitative**

In my surveys, 43% of farmers noticed an improvement in farm productivity after planting trees on their land. 12% of these farmers attribute these improvements to an improvement in soil fertility after incorporating nitrogen-rich tree leaves into the soil. Other farmers associate farm improvements with the reduction in soil erosion on their land. A few farmers in Middle Nyando also noticed improved coffee production after using trees for shading their coffee plants. The remaining farmers explained either they had not planted nitrogen-fixing trees in their fields or the trees were not yet mature enough to assess the effects.

Overall, relatively few farmers chose to intercrop nitrogen-fixing trees in their fields. Only 12% of farmers involved in an ICRAF project chose to intercrop trees in their fields. Farmers expressed concern that planting trees in their fields would reduce productivity of their crops and were unwilling to take such a risk. All farmers who have begun intercropping trees reported significant improvements to their productivity.

**Findings Quantitative**

For farms that are practicing agroforestry techniques, I found a slight improvement in farm yields in both Lower and Middle Nyando. After matching control and treated groups according to baseline parameters, I used a linear regression model to estimate the effect of agroforestry treatment on farm productivity. I replicated this analysis controlling for basic household characteristics within the regression and obtained the same general results and significance levels. See Appendix 2.4 for methodological details. The model estimates that Lower Nyando farmers involved in an agroforestry project improved their farm productivity, on average, by about 1,500 Ksh (US$19)\(^6\) per year when compared to the control group. A 1,500 Ksh increase is the equivalent of increasing an average Lower Nyando household’s maize yields by 35%. However, the standard errors in this analysis are quite large, with a confidence interval of -3,060 to 9,250 Ksh, showing this value is not statistically significantly different from zero (p=.678). Uncertainty was quite high in this study due to the small sample size. See Figure 5.3a for a visual descriptor of the significance of these findings. See Appendix 5.2 for more detailed values.

\(^6\) For all currency conversion, the July 2010 current rate of 80Ksh=USD$1 was used
In Middle Nyando, the results from statistical analysis show farm productivity increase by 2,100 Ksh (US$26) for treated units but again with a high standard error (p=.549). This increase is equivalent to improving an average Middle Nyando household’s maize yields by 20%. The 95% confidence interval for the predicted differences in the treatment versus control groups ranged from -4,605 to 8,850 Ksh, showing the large potential variance in these conclusions. See Figure 5.3b for a visual descriptor of the significance of these findings.

Location had a significant impact on farm productivity, with Middle Nyando farmers receiving, on average, 11,000 Ksh (US$137) more per acre from their farms than farmers in Lower Nyando (p=.001). This difference is largely due to variations in soil type and rainfall patterns across the two locations.

**Figure 5.3a.** Lower Nyando farm productivity significance levels. A simulation of the distribution of the treatment (dotted line) and control units’ (solid line) farm productivity in Lower Nyando. Treatment consisted of involvement in an agroforestry project for 2-4 years. The simulation generated 25,000 data points using estimated mean and standard error from the linear regression model and plotted results to show significance of the treatment effects reported.

**Figure 5.3b.** Middle Nyando farm productivity significance levels. A simulation of treatment (dotted) and control units’ farm productivity.
Discussion

The small improvement in farm productivity observed through the statistical analysis is consistent with qualitative observations. Most improvements in farm productivity from agroforestry techniques occur when nitrogen-fixing tree leaves are incorporated into the field. This technique had low uptake among farmers involved in these projects because farmers were unwilling to take risks with their farm productivity. Therefore, it is unsurprising that only a small improvement in farm productivity was observed. In addition, nitrogen-fixing trees take at least one year to begin improving farm yield [132]. Limited improvements are therefore expected among the farmers who have only been using agroforestry techniques for two years.

Despite the high standard errors within my quantitative analysis, my quantitative findings suggest a positive correlation between agroforestry involvement and farm productivity. My qualitative results largely support this claim, further strengthening the suggested positive relationship observed in my quantitative results. These conclusions support the literature’s findings that nitrogen-fixing trees improve productivity, as my qualitative results showed farmers with improved farm yields had been incorporating leaves into their soil. However, the exact reason for improved farm productivity among project participants is unclear as many factors may be playing into the difference in farm productivity across the control and treated group. Another major factor that may have influenced farm productivity is the improved agriculture training provided to those farmers in the treatment group. It is important to consider the other factors of involvement in a development project when interpreting the results presented above.

Income and Household Wealth

Agroforestry has also been argued to be an excellent way to improve household income. I expect that farmers involved in agroforestry development projects will have higher incomes, and therefore, will have improved total household wealth as compared to non-project participants. Agroforestry techniques can improve incomes through sales of tree seedlings, timber, fuel wood and fruit. I explore the literature on the subject of income improvements using agroforestry techniques to examine how other agroforestry projects have influenced household income and wealth. I then present my findings, concluding that agroforestry involvement does improve farmer wealth when there is access to a market or once trees reach maturity.
Literature Review

Agroforestry has been shown to improve farmers’ incomes in a number of different ways [47, 90, 134]. For example, mango sales in rural Kenya have provided families with an additional US$70 per year per tree [135]. Sales from medicinal trees, fuel wood, seedlings and timber also enhance farmer incomes [24, 134, 136]. Agroforestry also provides income diversity to smallholder farmers, a strategy that has been recommended to ensure adaptation to climate change and poverty alleviation for rural Africa [15, 24].

Despite the multitude of case studies demonstrating agroforestry successes in improving incomes, Garrity notes that agroforestry’s impact is often confined to local sites and projects [47]. Quinon’s study of agroforestry’s role in improving income found some income improvements, but the relationship noted was weak [134]. Therefore, a more systematic evaluation of agroforestry projects’ impacts on improving well-being and incomes is necessary [134].

Findings - Qualitative

Overall, farmers were most interested in trees’ ability to provide them with additional farm incomes. During focus group discussions, farmers ranked the potential income benefits from trees as the most helpful aspect of the trees on their land. Individually, over half of farmers in Lower Nyando reported having improved incomes after they planted trees on their land. Among farmers in Lower Nyando, who have had trees for four years, 87.5% of farmers reported income improvements. Fewer Middle Nyando farmers reported income benefits from agroforestry involvement, with only 40% seeing any benefits from their trees. Benefits were reported from the sale of fuel wood, timber, fruit and seedlings and through savings in food purchases due to an increase in farm productivity. For those farmers who had seen no improvement in their income after planting trees, most explained that their trees were still too young to provide any benefits. Farmers reported using the additional money from tree products to pay for their children’s school fees, additional food and household improvements. Farmers also used tree crops to help cope with exposures to specific climate-related hazards. During the flood and drought of 2009 and 2010, farmers cut trees for sale as timber and fuel wood.

Income opportunities: Farmers expressed interest in the opportunity to plant fast-growing trees for timber harvest, as timber and fuel wood were in high demand in the region. Fruit also appears to be a lucrative tree crop; only 18% of farmers in the area report producing fruit for sale, with average seasonal profits of 3,250 Ksh (US$40). To put these values in perspective, the average
national per capita income in Kenya is $452 (2009 data) [137]. Average per capita income for rural areas of Western Kenya are estimated to be much lower, at about 10,000 Ksh (US$126) [138]. Therefore, income benefits from fruit sales can be quite a substantial contributor to household incomes.

Currently, most cash income comes from small businesses that resell household products in small quantities, basket and rope making, fruit and vegetable sales, and buying and selling maize. Due to the extreme poverty in the region and poor infrastructure for transport, there are very limited income opportunities in the Nyando region.

Many people noted the potential for tree seedling sales to be expanded in this area as demand is increasing, but current seedling sales are low because of limited access to markets. Due to poor road maintenance, farmers cannot transport tree seedlings by vehicle and thus many of the seedlings get destroyed in transit or go to waste sitting unplanted in the nursery. Poor infrastructure was also noted as a constraint to other off-farm income opportunities including egg and fruit sales, as products get damaged on the way to market. The one farmer in the area who has had success with tree nurseries has access to a four-wheel drive car for seedling transport.

**Findings: Quantitative**

Because it is difficult to measure income among subsistence farmers, I used household wealth as a surrogate for income. Increased cash flow is expected to translate into higher wealth for a household. Household wealth, as measured by current livestock holdings, improved for Lower Nyando participants through involvement with an agroforestry project. Treated units in Lower Nyando had livestock holdings worth 24,000 Ksh (US$300) more than control units in the region, on average. This difference observed is significantly different from zero, with a 95% confidence interval of -3,400 to 50,850 Ksh (p=.092), see Figure 5.4a for a visual representation of this significance level.

For Middle Nyando, project involvement decreases average value of livestock holdings by 8,000 Ksh (US$100). However, this value is not significantly different from zero because the standard error for this estimate is very high, with a 95% confidence interval of -33,800 to 16,812 Ksh (p=.516). See Figures 5.4b for a visual representation of significance of these findings.

Location also had a clear impact on household wealth, with Middle Nyando residents having significantly more livestock holdings than their counterparts in Lower Nyando (location coefficient=29,000; p=.001).
Figure 5.4a. Lower Nyando- A simulation of the distribution of the treatment (dotted line) and control units’ (solid line) household wealth in Lower Nyando. Treatment consisted of involvement in an agroforestry project for 2-4 years. The simulation generated 25,000 data points using estimated mean and standard error from the linear regression model and plotted results to show significance of the treatment effects reported.

Figure 5.4b. Middle Nyando- Simulation of the treatment (dotted line) and control units’ (full line) household wealth. This suggests that farmers in the treated group actually have lower wealth than their control group counterparts, however, due to the extreme overlap of the two results the results are largely inconclusive.

Discussion

The Lower Nyando statistical findings agree with my qualitative observations about agroforestry’s ability to improve household wealth. The results that showed a larger improvement in wealth among Lower Nyando farmers than among Middle Nyando farmers, which supports the agroforestry literature’s hypothesis that agroforestry benefits take time to manifest for farmers. Lower Nyando farmers have been involved in agroforestry for a longer period of time than their counterparts in Middle Nyando [28].

It is not surprising that Middle Nyando farmers have not improved their wealth through agroforestry involvement, as these farmers do not yet have mature trees that can provide timber, fruit or fuel wood for sale. Due to their remote location, Middle Nyando farmers have also had less success selling tree seedlings to neighboring communities so have also been unable to receive substantial income benefits from this source as well. Lower Nyando farmers, on the other hand,
report selling fruit, timber, fuel wood and seedlings on a regular basis to local markets. From discussions with farmers in the area, it appears that the inconclusive results on wealth in Middle Nyando is largely due to a lack of infrastructure in the area, that is currently acting as a barrier to access markets for their tree crops.

The excitement farmers expressed in the income benefits from tree products likely stems from the limited opportunities for income generation in the area. As one elder farmer explained, “There is just no way to earn an income here...No one has money to buy anything from anyone else.” Fuel wood and timber appear to be excellent opportunities for income production, as 90% of farmers in the region are not currently self-sufficient with fuel wood [36]. Fuel wood and timber products can be sold to neighbors and therefore are not as dependent on market access to ensure financial returns to farmers. Finally, trees acted as a safety net for farmers when coping with climate-related shocks. Farmers were able to cut trees to sell for fuel wood and timber during intense times of need. Because few opportunities exist to generate additional income during extreme times of stress, the income opportunity provided by trees significantly helped some farmers obtain cash to purchase food during these times of stress.

As mentioned in the methods section, there are a number of problems associated with measuring income and wealth among farmers who are largely outside the cash exchange system. I collected a number of proxies for household wealth. Livestock appeared to be the most effective way to capture total household wealth, both from data analysis and in-field discussions. One may argue that more successful farmers or farmers using intensive agroforestry techniques may choose to store wealth in non-livestock forms. However, through observations, it appeared that most farmers still rely most heavily on traditional savings techniques of livestock acquisition, regardless of income level or farming practices used. It is also difficult to use wealth as a proxy for income, as not all increases in income are directly translated into increasing livestock storage. Farmers report using this income for other purchases as well. But most farmers interviewed report putting at least some of their additional income from agroforestry-related sales into livestock. In addition, my qualitative results also show an increase in farmer income, further supporting this correlation.
**Food Security**

Agroforestry has also been argued to improve the food security of subsistence farmers through improving farm yields and household incomes. However, this connection is explored less intensely in the literature. From the literature available, I expected food security, as measured by the number of months of hunger experienced and the intensity of hunger periods, to improve for those farmers involved in agroforestry development projects. However, the data I obtained were mixed leading to inconclusive results.

**Literature Review**

Agroforestry practices have been argued to improve household food security through improvements in income and farm productivity [131, 132, 134, 139]. One study found that improved yields from nitrogen-fixing trees reduced household hunger periods by two to three months [140]. In addition, fruits and nuts from agroforestry systems have also been shown to improve nutrition through providing key nutrients such as Vitamin A, especially to young children [135, 141]. Fruit trees also are able to provide caloric intake during droughts, as fruit trees are more drought-tolerant than other traditional food crops [136]. However, as I discussed in earlier sections, there are limited studies on the quantitative impacts of agroforestry practices on food security [134].

**Findings: Qualitative:**

In Lower Nyando, treated households experienced more frequent hunger periods relative to the control households (see Figure 5.5, Table 5.1). Hunger periods are defined as times when households had severe difficulties obtaining enough food to feed all household members. Overall, treated households in Lower Nyando experienced hunger 39% of the year, whereas the control group was hungry on average only 33% of the time. Treated farmers in Lower Nyando also reported using more types and more intense coping strategies than their control group counterparts. Intense coping strategies were defined as those strategies that had long-term negative impacts on household resources and included consuming seeds reserved for planting, selling oxen and farm tools for plowing, removing children from school, and migration. However, treated farmers in Lower Nyando did report having food from their own production for an additional two months longer than the control households. These results were similar in both household surveys and in focus group discussions.
In Middle Nyando, farmers involved in agroforestry projects reported experiencing less frequent hunger periods over the previous twelve months relative to control households (Figure 5.6). Overall, treated households in Middle Nyando experienced hunger 15% of the last year, whereas control households were hungry 23% of the time on average. Treated Middle Nyando farmers also reporting having food from their own production for approximately one month longer than the control group of farmers.

Figure 5.5: Calendar of the months Lower Nyando households experienced hunger periods. The red dashed line represents those households who received ICRAF support; the black solid line represents the control group. Treatment consisted of involvement in an agroforestry project for 2-4 years. Data comes from qualitative questions on household surveys. Harvest occurs in July 2009, however harvest was poor due to a failure of the rains in early 2009. Harvest for 2010 occurred in early June. N=116.

Figure 5.6: Calendar of the months Middle Nyando households experienced hunger periods. The red dashed line represents the treated group who received ICRAF support; the black solid line represents the control group. Treatment consisted of involvement in an agroforestry project for 2-4 years. Data comes from qualitative questions on household surveys. Harvest occurs in August 2009. Harvest for 2010 occurred in late June. N=116.
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**Table 5.1:** Summary of hunger statistics from Lower and Middle Nyando farmers. % Time Hungry represents the proportion of the past twelve months that households reported lacking resources to feed all members of the household, intensity of coping strategies is a weighted measure accounting for both the number and intensity of coping strategies used.

*Agroforestry's role:* Trees were used by a number of farmers to help improve income and food during periods of hunger. Income from fruit, timber and fuel wood was used to purchase additional food items. Many households relied on fruit production, especially papaya, to supplement diets during the drought. Farmers also cut down trees to produce charcoal or timber for sale, although many farmers noted that they understood that this practice is not a cost-effective use of their tree crops.

**Findings: Quantitative:**

I measured food security by combining the number of months households experienced hunger periods and the intensity of the coping strategies used using principal component analysis. See *Chapter Two* for more details. I found that food security decreased in Lower Nyando by 1.8% for households involved in an agroforestry project. The difference between the treated and control groups is not significant, as the data has a large standard error, so the treatment effect cannot be considered to be a variation from zero (95% Confidence Interval= -.5 to .38; p=0.78), see *Figure 5.7a*. In Middle Nyando, there appears to be an improvement of 9.1% in food security for project participants (p=0.14). The Middle Nyando results prove to be more statistically significant, with a 95% confidence interval of -.1 to .72, see *Figure 5.7b* for visual representation of significance. Location also affected food security; as Middle Nyando farmers were food secure 9.4% more of the year than their Lower Nyando counterparts.
Figure 5.7a. Lower Nyando- A simulation of the distribution of the treatment (dotted line) and control units’ (solid line) food security in Lower Nyando. Treatment consisted of involvement in an agroforestry project for 2-4 years. The simulation generated 25,000 data points using estimated mean and standard error from the linear regression model and plotted results to show significance of findings.

Figure 5.7b. Middle Nyando- Simulation of the treatment (dotted line) and control units’ (solid line) food security

Discussion

The improvements in food security among Middle Nyando farmers support the hypothesis that there is link between agroforestry project involvement and food security, but Lower Nyando results do not follow a similar pattern. My quantitative findings are consistent with the qualitative findings I obtained through interviews and focus group discussion. Lower Nyando’s decrease in food security for project participants may be due in large part to environmental factors, as the control group in Lower Nyando is found slightly farther from the riverbed and was therefore sheltered from the most recent flood in 2010 that had substantial impacts on food security in the region (see Chapter Four). This difference in location of the control and treatment groups was minor, but future randomized trials are needed to verify the results seen in this section.

It is also possible that the signal of food security was muted among the noise of the data due to the small sample size. The literature suggests that agroforestry improves food security indirectly by improving farm productivity and household wealth. In Chapter Three, my results supported this
claim by showing that food security is positively correlated with household wealth and farm productivity. My data in this section revealed only weak correlations between agroforestry and farm productivity and household wealth. Because these correlations were small, the resulting impact on food security may have been indeterminable amongst the noise of the small data sample. Despite these inconclusive results, from my findings in Chapter Three and my earlier results in this chapter, I expect that, over time, food security of agroforestry participants will improve as farm productivity and household wealth increase.

From this analysis, it is also clear that food insecurity in the region is particularly high. These findings are consistent with other studies in the region [39]. This observation is important in considering the generalizability of this study’s findings, as many other areas around the world do not experience this intensity of food insecurity.

**Conclusions**

This analysis showed that agroforestry techniques do have the potential to improve farmers’ well-being, particularly through improving farm productivity and household wealth, as well as reducing soil erosion and time spent collecting fuel wood. In considering the results presented here, it is important to recall that this study was conducted with farmers involved in agroforestry practices for only two to four years. The literature explains that agroforestry benefits typically take at least two years to begin to manifest [28]. It is therefore unsurprising that many of the quantitative trends presented in this analysis were small. The fact that most of these trends were positive and supported the qualitative results collected is promising in forecasting future impacts as the trees continue to mature.

The initial section on agroforestry perceptions also provides helpful insight into the affects of agroforestry projects, as farmers often are hesitant to adopt ambitious agroforestry techniques, thus further slowing the benefits of agroforestry practices. This analysis also points to the importance of collecting baseline data for evaluation projects, as this study would have been substantially more effective if data from before and after agroforestry involvement were available. Despite these limitations in the study design, the robustness of the combination of my qualitative and quantitative results show that agroforestry techniques do have an important impact on farmers’ well-being. These effects can be further enhanced if agroforestry development projects are implemented more effectively, a discussion I pursue in the following chapter.
In my quantitative analyses, it is important to reiterate that my results reflect the impact of engagement in an agroforestry development project. Thus, the trends may be impacted by other elements of involvement in such a project. It is not possible from the data available to argue authoritatively that changes seen in farm productivity, household wealth and food security are entirely caused by agroforestry techniques. However, my results are useful because most expansions of agroforestry practices are based on similar agroforestry projects as those reviewed in this case study. These results can shed light on some of the impacts that similar agroforestry development projects have.
Chapter Six: Conclusions and Recommendations

This chapter summarizes and ties together the key conclusions made through my research process and analysis. I begin by reviewing my key findings. I then discuss the relevance of these findings to the scholarly literature on climate change vulnerability and agroforestry practices. Finally, I conclude with a set of recommendations to improve future agroforestry projects and help farmers better adapt to future climate change.

Summary of Findings

In the research reported here, I set out to analyze whether and how agroforestry projects can reduce subsistence farmers’ vulnerability to climate change. I structured my analysis using Turner et al.’s (2003) vulnerability framework, which divides the concept of vulnerability into exposures to climate shocks, the sensitivity of the system to these shocks, and the resilience of the system to deal with future exposures [8]. I used household surveys, in-depth interviews and focus group discussions with farmers in rural western Kenya to investigate my questions of interest. This mixed methodological approach provided the analysis with a rich and comprehensive view of farmers’ lives in this area.

I opened my analysis with a hypothesis from the literature that an effective way to reduce farmers’ vulnerability is through improving general farmer well-being. At the beginning of my field study in western Kenya, I established through discussions with farmers how they define the concept of well-being. As I discussed in Chapter Three: Conceptualizing Well-Being, farmers are more focused on the material determinants of well-being, rather than an abstract concept of well-being. Farmers primarily emphasized the importance of improving their income, asset stores and food security as key pathways to improving their well-being. In addition, most farmers agree that their activities need to become more environmentally sustainable and better able to withstand climate-related hazards. The most effective way to achieve these improvements, according to farmers, is through improving farm productivity, income, and the knowledge and resources available to farmers.

In Chapter Four: Climate-Related Hazards, I explored farmers’ current sensitivity to climate-related hazards, as a proxy to better understand how future climate change will affect farmers’ well-being. From my analysis, it is clear that farmers are not currently coping with climatic hazards in a sustainable way, as they are forced to sell their farm tools, consume seeds reserved for planting and
lease their land during periods of hunger. As these hazards become more frequent and intense, these unsustainable coping strategies will drive farmers further into poverty.

I found from discussions with farmers that the most effective way to adapt to future climate-related hazards will likely be through general adaptation measures, rather than investing in specific adaptation techniques. These measures include improving farm productivity, household income, access to markets, agricultural knowledge, and the environmental health of cropping systems. This conclusion was consistent across sub-locations and households of varying degrees of wealth. This suggests that general well-being improvements can be a universal strategy to help farmers’ reduce their vulnerability to climate change.

Farmers believe that more specific adaptation measures, such as drought-tolerant plants and dam infrastructure, are potentially damaging when dealing with the wide variety of climate-related hazards they face. Some specific adaptation measures do appear promising to cope with particular climate-related hazards. However, they require capital investments for installment and upkeep that farmers currently do not have. Farmers are unwilling to take out loans for these investments because of the uncertainty related to climate change predictions. There is a clear need to do place-based analyses of specific adaptation strategies that also examine whether adaptation options would be helpful across a wide range of climate-related hazards. This was evident from the discrepancies between my two sub-locations on the most effective specific-adaptation strategies to employ. A one-size-fits-all approach does not accurately capture the different needs of individual communities or address the issues brought about by different climate-related hazards.

I argue that development initiatives should focus on improving the general well-being of farmers through improving and diversifying incomes and increasing farm productivity, rather than on supporting projects that are focused solely on specific adaptation measures. This will allow farmers to use the additional capital gained from increased income streams and farm productivity with their own ingenuity to find the most effective way to adapt to future changes. Farmers expressed an interest in receiving advice and suggestions for adaptation strategies, but they also stressed their desire to be in control of the specific projects they choose to implement on their land. As discussed in Chapters Three and Four, I found extensive support for my initial hypothesis that improving general farmer well-being is likely to be the most effective and comprehensive way to reduce farmers’ vulnerability to climate change.

I then examined agroforestry’s potential contribution to improving farmer well-being and improve farmers’ resilience to future climate changes. There is a multitude of ways to improve rural
livelihoods. My analysis focused solely on agroforestry techniques because agroforestry is frequently cited for its potential contribution to climate change adaptation, yet there are few studies examining how it would do so. In Chapter Five: The Role of Agroforestry in Reducing Farmers’ Vulnerability to Climate-Related Hazards I showed that involvement in an agroforestry development project improved farmers’ well-being through increasing farm productivity and household wealth. Agroforestry also provided steady income for a number of agroforestry practitioners through the sale of fuel wood, timber and fruit. Results on agroforestry’s impacts on food security were less clear, as agroforestry involvement improved food security for Middle Nyando farmers but in Lower Nyando the results were inconclusive. However, in Chapter Three, my findings suggest that higher farm productivity and income are closely correlated with enhanced food security. These findings suggest that agroforestry also improves food security, but indirectly through improved farm productivity and household incomes. Finally, agroforestry also improves farmer well-being by leading to substantial time saved in fuel wood collection. These savings, in turn, help already overburdened women reduce their weekly workload and devote more time to income-enhancing opportunities.

I also found that involvement in agroforestry improves the environmental sustainability of agricultural practices in the face of climate change. My findings in Chapter Five suggested that agroforestry substantially decreases soil erosion rates, which in turn improves soil fertility, water infiltration, and soil structure. Farmers frequently noted the planting of trees as helpful when exposed to climate-related hazards because the trees’ roots protected their fields from soil loss during floods and heavy rains.

Agroforestry also provides specific coping options to farmers when faced with climate-related hazards. Some farmers reported having fruit from their trees as their only steady source of sustenance during the floods, as other crops were underwater or had been washed away. During the drought, many farmers reported selling fuel wood and timber to produce additional income for food purchases. Their trees did not prevent these farmers from suffering from the impacts of the climate-related shocks entirely. But the alternate coping strategies provided by trees allowed farmers additional flexibility in their management of the climate stresses they faced.

From my extensive analysis, I concluded that agroforestry techniques help farmers reduce their vulnerability to climate change. Most importantly, agroforestry can help improve farmers’ well-being through farm productivity and income opportunities, but it also provides some more specific coping strategies that are helpful during particular climate-related shocks.
Discussion

At the outset, I cited a number of arguments from the literature suggesting that agroforestry can be an effective tool to help farmers reduce their vulnerability to climate change [2, 142]. My findings provide quantitative results, supported by qualitative descriptions, on how agroforestry techniques can help farmers mitigate their vulnerability to climate-related hazards, both through improving their well-being and through specific coping measures.

My results challenge the trends in current scholarship and literature that differentiates between well-being and livelihood security. The literature distinguishes livelihood security from well-being because livelihood security focuses on a minimum level of security all people should be able to obtain even in the face of climate-related hazards. However, the farmers I interviewed defined their life goals as a process of continuous improvements. This focus on improvements is explored extensively in the literature on creating improvements in workplace productivity [143]. The focus on continuous improvement is not a new phenomenon, but it does not appear to be discussed in detail in the literature on well-being.

Farmers also expressed interest in improving their well-being even when affected by outside shocks and stresses. This definition blurs the lines between well-being and livelihood security by taking components of each. By establishing the way farmers’ frame this discussion, I was able to avoid the common pitfall in development literature of formulating questions and solutions that are not relevant to the farmers themselves. Future analyses on climate change vulnerability should consider in more detail the way the individuals in their study frame well-being to better understand the what of their vulnerability analysis. I found that the most helpful way to conceptualize vulnerability was to consider the determinants of well-being as the object that is vulnerable to climate change.

I also found that farmers put substantially more emphasis on the fundamental importance of food security than did the literature. This finding should provide a reminder to development scholarship of the importance of dealing with basic necessities when considering more complex well-being improvements such as literacy rates, reproductive health and agroforestry techniques. The significance of such topics to rural development is quite clear and has been shown in many development projects. However, it is paramount that development projects operating in food-insecure areas show how they can help households improve the determinant of well-being most important to them: their food security. This lesson is especially relevant to agroforestry development projects, as farmers are asked to invest substantial time in tree seedling care before any
benefits are accrued. For households that are still struggling to ensure they have enough to eat, tree seedlings and other long-term investments are often neglected until this need is met.

Farmers are also aware that they will need to improve their well-being in the face of climate-related shocks and stresses. They have noticed a substantial change in climate trends over the last thirty years, with farmers complaining of an increase in droughts and rainfall variability. These observations are consistent with what current climate change models predict [5]. To the farmers interviewed, rainfall variability was the most worrisome aspect of any changes in climate or weather patterns noticed over the last thirty years. Many farmers cite tree planting as a solution to the climate variations they have observed. It is unclear whether farmers believe in this strategy or are merely repeating solutions provided by the Kenyan government. Regardless, most farmers are optimistic that personal actions can reduce the effects of global warming. This provides an opportunity for future projects to work with farmers’ interest in tree planting to support climate change mitigation while also improving farmer and environmental well-being.

My quantitative and qualitative results both largely support the consensus in the literature that agroforestry involvement improves farm productivity and household wealth [114]. However, my findings highlight the length of time it takes for agroforestry practices to benefit farmers, as many of the impacts I reported were quite small. I expect the magnitude of improvements in farm productivity, household wealth and food security in my study area to increase as trees mature. Future studies of this area would need to confirm such an assertion. As much of the literature on agroforestry focuses on longer-term studies, my analysis provides a better understanding of how agroforestry projects affect farmers in the first two to four years of project implementation. My findings underline the need to provide agroforestry techniques in collaboration with other development initiatives that can deliver short-term benefits to farmers while waiting for the investments in trees to pay off. Short-term projects, such as basic agriculture training or access to farm tools, could be made dependent on tree seedling success to motivate farmers to maintain their trees during the early, most sensitive, stage of the trees’ lifecycle.

My study was particular to a specific agroforestry project and location. However, my conclusions can still provide significant guidance to future studies on reducing farmers’ vulnerability to climate-related hazards because I showed how the Turner et al. framework can be used to conceptualize vulnerability in a field study. In addition, my findings suggest that it is likely that for extremely poor households, improving general well-being will be the most effective way to enhance resilience to future hazards associated with climate change. This finding can be generalized to other
rural subsistence-farming communities, as the most basic problems faced by farmers during climate-related hazards are widespread. Whether this finding can be applied to more food secure and successful small-scale farmers remains to be explored. Future studies should evaluate the effectiveness of improving well-being as a strategy to reduce vulnerability to climate-related hazards among this cohort of wealthier farmers. My findings on the most effective specific adaptation measures should not be generalized to other populations, as my findings clearly showed the need for place-based analysis of effective specific coping strategies. I found that there is far more diversity in the potential options and potential consequences of specific of adaptation measures. Instead, this study should serve to highlight the need to do location- and hazard-specific analyses of the most effective specific adaptation strategies.

The methodological approach I developed for my evaluation can also act as a guide for similar studies on climate change adaptation. I entered the research process with a number of literature-based hypotheses on effective climate change adaptations but allowed farmers’ local perspectives to fully define the goals and the most effective means of adaptation. This approach allowed me to evaluate adaptation opportunities from the perspective of the farmers who ultimately carry out and experience the consequences of climate-related hazards. Studying impacts of current climatic hazards to simulate effects of future changes also helped investigate current and potential future vulnerabilities within a community. As it is impossible to create a model that can be trusted to perfectly replicate the impacts of climate change in the future, this method appears to be a valuable way to assess potential vulnerabilities to environmental conditions that do not yet exist. Finally, my methodological choice to use quantitative data to support my qualitative findings provides a rigor to my study while also providing a descriptive and realistic picture of farmers’ lives on the ground.

Fully engaging farmers in the research process also significantly enhanced my findings. Farmers also report benefiting from my research process because it provided them with an opportunity to discuss constraints to their well-being and think about potential solutions. Communities found that discussions of vulnerability allowed them to reflect on their current farming practices and engage in a community conversation of future adaptation options. This dialogue really flourished when I presented my initial findings to the farmers in a community gathering I organized at the end of my stay. See Figures A1.5 and A1.6 in Appendix 1.1. Discussions with farmers at this community gathering stressed the responsibility field researchers have to provide feedback and results to the participants in their study. As the local chief explained to me, “many
scientists have come here, but you are the first to return with results.” I hope that future studies can continue to build on this approach and engage farmers more fully throughout the research process. This will allow the scientific community to further the dialogue with farmers in how we can work together to ensure environmental sustainability and well-being improvements in the face of future climate-related hazards.

Recommendations

My findings show that even in a non-ideal setting, with low uptake of intensive agroforestry techniques and low seedling survival, farmers are still able to obtain substantial benefits from agroforestry involvement. These conclusions beg the question, what can be achieved with even more effective implementation? There are few analyses of agroforestry development projects currently available for review [28]. In order to enhance the effectiveness of agroforestry practices in improving farmer well-being in the face of climate-related hazards, I recommend the following policies for future agroforestry development projects:

1. **Involve farmers in the project planning process:** Farmers’ input should be used to ensure that the development project is targeting what is most relevant to project participants. Prior to beginning new development projects, discussions between project developers and local communities should take place to ensure both parties understand the goals of the project and the most effective way to accomplish them within the local context. Many researchers also emphasize the importance of farmer involvement in project development to ensure long-term sustainability and improve adoption potential [47, 107].

2. **Pair agriculture and agroforestry training:** Agroforestry is a long-term process and, as I showed in this analysis, benefits can take a long time to accrue. Therefore, improving the sustainability of agroforestry projects is key. Only 44% of seedlings provided to farmers in this project analysis survived. Farmers attribute their lack of motivation to care for tree seedlings to multiple factors such as, the long wait that is required to see benefits from agroforestry practices, the more immediate pressures of hunger, illness and child education that take priority over tree care, and the risk associated with investments in trees. These findings are consistent with other studies of agroforestry practices [144]. Therefore, it will
be important to include shorter-term benefits to farmers that are coupled with agroforestry implementations so farmers do not get discouraged during the initial project stages.

Pairing agroforestry and agricultural training is an excellent opportunity to provide short-term benefits from improving basic agriculture knowledge with long-term extension for agroforestry practices. Training is an especially important component of agroforestry projects because agroforestry techniques are knowledge-intensive and location-specific [26, 111]. In addition, improving the availability of information on agroforestry has been shown to enhance the uptake of these techniques [139]. I also found that if farmers understand the potential of their trees to enhance their well-being, they put more concentrated efforts towards tree care and management, giving further reason to focus on the training aspect of agroforestry programs.

At the same time, many farmers have never received any formal agricultural training. Improved agricultural training has also been cited as an important way to improve farmers’ adaptation to climate change [15, 124]. Any training provided should focus on the direct needs of the individual community and be structured in a way to provide substantial time to respond to questions brought up by individuals. Training should be provided on-site, as farmers are often unable to leave their farms for extended periods of time due to other household duties. Finally, training should be provided during a time of the year that is least disruptive to their farming cycle. To improve the cost-effectiveness of such a training model, local extension officers could be trained to improve information access on a daily basis and to encourage community buy-in, as this method has been proven to be an effective and low-cost technique for information dissemination [110]. The potential for mobile phone communication to aid knowledge transfer is an area that also may help with this knowledge gap [145].

3. **Improve market accessibility to enhance income-generating opportunities provided by agroforestry techniques:** As my analysis showed, one of the most effective ways to reduce farmers’ vulnerability to climate change is through improving incomes of rural farmers. Because tree crops are more resistant to climatic shocks, they can provide support for farmers during these times of stress. Agroforestry techniques have the potential to provide income to farmers through the sale of fuel wood, timber, fruit and seedlings; but there must be a focus on the income-generating opportunities trees can provide during the
initial stages of the project. In comparing the benefits derived from agroforestry involvement across my two sub-locations, market access played a key role in improving household incomes due to agroforestry projects. Therefore, market access needs to be improved. This can be done on a governmental scale through improving infrastructure or, more locally, through establishing cooperatives that pool resources to access improved transportation. Infrastructure is often cited in the literature as a key component of rural development [146]; however through discussions with farmers it appears that local pooling of resources to rent or purchase motorized transport may also prove successful.

4. **Access to farm implements and capital:** Lack of access to farm implements and capital were listed as key constraints to overall farm productivity in the Nyando region, and almost no one has access to small-scale loans in this area. Although not directly related to agroforestry, any major constraint to farm productivity reduces farmers’ ability to cope with climate change. In addition, by improving access to loans and to farm implements through an agroforestry development project, farmers are able to see tangible benefits in the short-term from their project involvement before their trees have matured. This coupling of access to credit and to agroforestry training has been found to be an effective way to reduce vulnerability to climate change in other studies [147].

5. **Organize educational farm-visits to successful agroforestry projects to increase adoption of agroforestry techniques:** There is substantial room for the expanded use of agroforestry techniques in improving farm productivity, as uptake of intensive agroforestry techniques was low among farmers. The key reason for this low uptake was that farmers perceive these techniques to be high-risk. All farmers interviewed who engaged in intensive agroforestry techniques had seen the benefits on someone else’s farm before implementing the techniques themselves. To improve agroforestry uptake, supporting farm visits to nearby successful agroforestry projects appears to be most effective and cost efficient [4].

Agroforestry, like any single coping strategy, will not prove to be the silver bullet to climate change adaptation. However, I found that agroforestry practices do have substantial potential to help farmers improve their well-being and the environmental sustainability of their farms. Through these improvements, and by providing some additional specific adaptation strategies, agroforestry
practices can reduce farmer vulnerability to climate change. By adopting the recommendations outlined above, I hope that future agroforestry projects can contribute, as a part of larger development initiatives, to helping subsistence farmers better cope with future climate change.
Appendices

Appendix 1.1: Pictures from the Field

Figure A1.1: An example of intercropping agroforestry techniques in practice. These nitrogen-fixing trees are approximately three years old, on a farm in Lower Nyando.

Figure A1.2: A typical farmer’s household in Lower Nyando.
Figure A1.3: The effects of soil erosion in Lower Nyando. Walter is indicating where soil levels used to be.

Figure A1.4: Gullies formed due to intense soil erosion in Lower Nyando.
Figure A1.5: Middle Nyando farmers explaining their goals for future adaptation strategies and thanking my research team for sharing our findings at the community gathering at the conclusion of my stay.

Figure A1.6: Lower Nyando women thanking my research team for organizing a community gathering where they were able to sit together and discuss current problems facing their households and the potential solutions moving forward.
Appendix 2.1: Project Background

A summary of key outcomes from the COMART 2008 Project can be seen in Table A2.1. This project was in coordination with CARE-Kenya, who provided a one-day training on general farming techniques to all community groups. In addition to the deliverables outlined in Table A2.1, ICRAF staff also worked with each community group on a weekly basis for between six and nine months on community tree planting on degraded land (Lower Nyando) and building of terraces for soil erosion control (Middle Nyando). To motivate farmers to work on community projects, a food-for-work project was implemented wherein the group received 180 kg of maize per day of community work each week.

<table>
<thead>
<tr>
<th></th>
<th>Number of Seedlings in Tree Nurseries</th>
<th>Community Seedlings Planted</th>
<th>Individual Seedlings Planted</th>
<th>Training Sessions Provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Nyando</td>
<td>5,000</td>
<td>3,500</td>
<td>4,600</td>
<td>5</td>
</tr>
<tr>
<td>Middle Nyando</td>
<td>15,000</td>
<td>0</td>
<td>8,900</td>
<td>5</td>
</tr>
</tbody>
</table>

Table A2.1: Summary of key deliverables provided by ICRAF between July 2008 and August 2009 to 58 small-scale farmers in the Nyando District of Kenya during the COMART 2008 Project implementation. Note- no community seedlings were planted in Middle Nyando because the focus was on terrace building, not community land restoration.

Exact numbers from the WKIEEMP Project were not available, but these farmers also received between 200 and 300 seedlings per household, agroforestry training and food for work on community tree planting. These activities took place between 2006 and 2008.

For all projects, the primary species of trees provided were: *Acacia albida, mellifera and ploycantha, Albizia coreria, Calliandra calothyrsus, Casuarina equestifolia, Cordia abyssinica, Gliricidia sepium, Grevellea robusta, Markhemia lutea, Senna siamea,* and *Warburgia ugandensis.*

![Figure A2.1: Map of Lower Nyando area. ICRAF project sites are identified with red dots. Map courtesy of Joash Mango, ICRAF](image-url)
Appendix 2.2: Farmer Selection Notes

My research team and I surveyed 45 out of 51 households involved in the COMART 2008 Project, with six farmers that could not be located. We also administered the surveys to two new community groups that had been recently identified to participate in the next phase of the COMART 2010 project. These groups had been selected by ICRAF staff for their proximity to previous participant groups and for their lack of involvement with other developmental organizations. Each household among the COMART 2010 project was also interviewed resulting in a total of 43 households. During the COMART 2008 project, seedlings but no training were provided to 15 households in the Middle Nyando region. Eight of these neighboring households were interviewed, but later omitted from the analysis because they did not fit well into a treatment or control category.

Because all farmers interviewed in the COMART projects had been involved in agroforestry technique for only 0-2 years, an additional group of ICRAF participants from a previous project were also interviewed. A total of 31 households who had been involved in agroforestry techniques for four years were interviewed from ICRAF’s “WKIEMP” agroforestry project implemented in 2006.
Appendix 2.3: Data Measurement Notes

*Household wealth:* Incomes could not be measured directly in this economy because it is largely a trade-based economy with many transactions occurring outside of the cash system. In addition, because households engage in subsistence farming, they do not rely on cash flows to provide food for their households. Therefore, this analysis chose to use wealth as a proxy for expendable incomes, as it is expected that farmers with excess income flows invest in household wealth. As was discussed in the body, farmers most commonly use livestock to hold household wealth. Farmers explain that they choose to invest in livestock instead of keeping cash because they feel that they would spend the cash on non-essential goods, such as household improvements, while they are inclined to save livestock for times of need. According to the farmers, it is against Luo customs to sell livestock unless faced with major hardships; therefore farmers are more conserving of their livestock holdings than their cash. A few farmers have begun saving in mobile accounts like Empeza, which allows individuals to transfer cash via their mobile phones, but they still report the tendency to spend this money before extreme periods of hunger. Consequently, they keep the majority of their wealth in livestock holdings.

Initially, household amenities and structure were also going to be used as another proxy for household wealth. The type of roof, wall and floor materials were also collected to use as indicators. However, due to limited variability among households, when this data was combined with livestock value using Principal Component Analysis, it was found that all significant variation in the data was captured in the value of livestock holdings. Because the addition of the household structure data only complicated the interpretation of results, I chose to leave them out for improved clarity of results.

*Food Security:* A hunger period was defined to survey participants as a “a time when there were serious difficulties producing or purchasing enough food to feed all household members.” Coping strategies were divided into two subclasses of ‘non-erosive’ and ‘erosive’ coping strategies as defined by De Waal in his extensive work on famine response [99]. Coping strategies included in the ‘non-erosive’ category included: reduction in the quantity, quality or number of meals, asking for help from a government, church or NGO and receiving aid from family or community members. Erosive strategies included the sale of livestock or possessions, children from the house attending school less frequently, consumption or sale of seeds reserved for planting, borrowing money, forced migration from the farm and casual labor that interfered with one’s own farm production.

*Agroforestry Involvement:* Both the height and number of trees were included in the agroforestry parameter because the impact of agroforestry on fuel wood collection times and soil erosion is a function of both the density of the trees and the size of the tree.

*Soil Erosion:* Soil erosion type was distinguished among three subcategories of increasing intensity: rill, sheet and gully. After noting the type of erosion present on the field, the intensity of the erosion was also evaluated on a 3-point scale (1 being low severity, 3 being extreme erosion). The intensity scale was a subjective measure of the observer but took into account the depth and frequency of observed erosion. I combined these two measures by multiplying the two observations to obtain a scale of erosion between 0 (no erosion) and 9 (extreme, gully-erosion) for each farmer. An alternate scale for the two variables was also used to ensure reliability of the weighting scheme. The alternate method assigned on a point scale, with rill erosion taking the values of .2, .3, and .4 depending on the corresponding erosion intensity observed. Sheet erosion ranged from .5-.7.
and gully erosion, because of its severity, was assigned 1, 1.2 or 1.4 on the weighting scale. This scale of erosion gave more weight to those farmers with gully erosion on their farm. Despite the differences between the two measures, the correlation between the two was .954. Upon replicating all tests with this measure of erosion, almost identical results were obtained.

**Appendix 2.4: Data Analysis Notes**

**Quantitative Analysis:**

*Matching:* Using the statistical software R, the full matching option (distance= “full”) in the MatchIt program was used to match on five basic household parameters (household size, land tenure, household head educational level, soil type and gender of household head) [45]. The log of the household size was taken to improve the balance of the matched results, as household size spanned a large range from 1-17. Education was collapsed into six subclasses ranging from no education to post-secondary education. Balance was improved after matching for all variables except education; however this tradeoff was accepted, as the improvements across the other variables were quite substantial.

*Linear Regression:* Due to potential differences based on the climates of the two regions, separate intercepts were estimated for each location. Treatment effect was also calculated separately for each location to account for potential differences in services received from ICRAF between Lower and Middle Nyando. P-values were estimated directly from the linear regression for Lower Nyando results. For Middle Nyando significance tests, a random data generator from the Zelig software package [46] ran a normal distribution of the standard errors observed in the model for each location’s treatment effects. From these distributions, the overlap was estimated between the treated and control distributions.

*Omission of surveys:* Eight farmers that received seedlings but no training were not included in the analysis of results because they did not receive the same treatment as other ‘treated’ households and, therefore, could not be accurately combined with this group. Because the omitted group was such a small number of farmers, additional analysis of this group was also not possible. The three farmers that were left out of the survey clearly did not fit into the target population of ICRAF projects. All farmers owned televisions, had large well-established homes and had received a university education. Most household income came from remittances from their children overseas. Therefore, to include them in an analysis of project treatment effects would have unnecessarily biased the data.

**Appendix 3.1: Calculating Food Security Relationships**

To calculate the correlation between food security and the variables farmers identified as impacting their food security, farmers’ primary indicator of well-being, I used a simple least-squares linear regression setting food security as the outcome variable and farm productivity, household wealth, household gender, educational status of household head, land ownership and income diversity as the independent variables. Measurements of variables are discussed in Chapter Two-Methods.

In measuring food security, a principal component analysis (pca) was used to combine two different measurements of food security [148]. The regression produced the data reported in Table A3.1. For ease of understanding, these pca regression scores were converted into percent change by
dividing by the total range of pca scores (3.46 for Lower Nyando; 2.8 for Middle Nyando; 3.46 for entire group). When calculating the percentages for sub location, the specific range of pca scores of these regions were used. Full details of the regression can be seen in Table A3.1 prior to conversion of pca scores into percentages [148].

<table>
<thead>
<tr>
<th>Numbers in raw pca scores</th>
<th>Farm Production</th>
<th>HH Wealth</th>
<th>Male-Headed HH</th>
<th>Education of HH Head</th>
<th>Hold Title Deed to Land</th>
<th># of Income Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower Nyando Food Security</strong></td>
<td>.027 (p=.003)</td>
<td>.002 (p=.3)</td>
<td>.20 (p=.22)</td>
<td>.009 (p=.6)</td>
<td>.226 (p=.054)</td>
<td>.022 (p=.25)</td>
</tr>
<tr>
<td><strong>Middle Nyando Food Security</strong></td>
<td>.01 (p=.013)</td>
<td>.006 (p=.009)</td>
<td>.917 (p=.021)</td>
<td>.032 (p=.258)</td>
<td>.113 (p=.61)</td>
<td>-.053 (p=.711)</td>
</tr>
<tr>
<td><strong>All Households Food Security</strong></td>
<td>.012 (p&lt;.0001)</td>
<td>.004 (p=.007)</td>
<td>.41 (p=.009)</td>
<td>.019 (p=.21)</td>
<td>.20 (p=.20)</td>
<td>.015 (p=.84)</td>
</tr>
</tbody>
</table>

Table A3.1: PCA scores of food security analysis. Improvement in food security due to different components of livelihoods measured in raw principal component analysis scores. Farm productivity measured in 1000 Ksh increase in economic value of seasonal farm production; HH Wealth measured in a 1000 Ksh increase in livestock holdings; Education of HH Head measured in increasing educational attainment of HH head by one year; # of Income Sources measured in increasing income diversity by one source. HH=Household. Lower N= 60; Middle N=56; Total N=116.

To better understand the impacts of changes in farm productivity and household wealth had on farmers' food security, I did further analysis to covert these pca scores into more relevant values. As presented in Table A3.1, the improvement in food security is correlated to a 1,000 KSH increase in farm productivity or wealth. The numbers reported in-text show the predicted affect on food security if a household moved from the 25th quartile of farm productivity or wealth to the 75th percentile, holding all other variables at their mean values. From these results, 10,000 simulations are run to estimate the p-value using the SD and mean provided in the regression output. The difference in pca calculated from this analysis was then converted into % change in food security in the same way as described above.

This form of data analysis assumes that households exist with mean-values in all other variables except for the manipulated variable (farm productivity or wealth). It is important consider this assumption when making inferences from the results, however it is a assumption made in other statistical modeling of this kind.

Appendix 4.1: Adaptation Options Matrix

The matrix rankings were creating using feedback from both farmers and the literature to assess both the farmers’ perceptions of potential benefits and the literature’s experience using such adaptation strategies in other regions.

General adaptation strategies:

Farmers were very clear in their interest in improving off-farm incomes, agricultural knowledge, and market access as effective ways to improve their ability to adapt to climate-related hazards. This largely supports much of the adaptation literature [12, 74, 92, 95]. Farmers were slightly more hesitant to diversify their crop species, but after community discussions decided this could be a beneficial technique. Much of the literature suggests crop diversification as to take advantage of different crop’s ability to thrive under different weather conditions [104].
Farmers were also very enthusiastic about the potential of improving tree cover to reduce soil erosion, improve soil quality and soil fertility. This is also in agreement with the literature, particularly around agroforestry practices, that increasing vegetation cover can help farmers reduce their vulnerability to climate-related hazards [24]. As mentioned earlier in the paper, it is possible that the farmers’ excitement over tree planting could be due to the affiliation of the research team to ICRAF. However, even farmers who were not aware of our affiliation to ICRAF cited tree uses as a potential adaptation strategy, so I believe that this enthusiasm was not entirely due to biasing of responses.

**Specific Adaptation Measures:**

**Water storage facilities:** Farmers had heard of wealth farmers in the area using water storage tanks to provide water to their high-value crops during times of drought or low rainfall. They were also interested in water storage ponds to hold water during droughts and divert excess water during floods. Their interest in water storage facilities as a potential adaptation measure is echoed in the literature [82, 88].

**Dams, Levees and Trenches:** Farmers were also interested in the potential to expand their trench and dam systems to better deal with future floods. However, the literature warns that these types of infrastructure can have long-term negative impacts by disrupting normal river flows and hurting down-stream water users [74]. In addition, this type of infrastructure is very expensive to maintain [74].

**Community Emergency Committees:** Farmers had not considered emergency community committees, but were interested in more organized responses to severe shocks in the region. The literature suggests community-led emergency committees as an effective way to provide fast, targeted response to local emergencies [15, 74]. However, this will require substantially more collaboration across levels of governmental administration [15]. Emergency committees will also only be effective for immediate relief efforts and can not be expected to deal with the yearly food insecurities households deal with due to rainfall variation.

**Drought Resistant Crops:** Farmers were largely unsupportive of the new drought-resistant crops some NGOs had suggested in the region. Farmers found that their productivity during years of average rain was much lower if they planted drought resistant crops, and due to the unreliability of weather forecasting in the region, they did not feel comfortable relying on forecasts to know if the upcoming season was going to be a dry one. Much of the development community is focusing on drought resistant crops [149], but farmers reported not being interested in using the seeds, even if they were provided for free, unless they were sure that the year was going to be a drought.

**Small-scale Irrigation:** Farmers were interested in small-scale irrigation options, as some farmers in the area had used them with some success. However, farmers did not have the capital to purchase the materials and were unwilling to take out loans of the size needed to purchase such equipment. Small-scale irrigation has been shown to be effective in other regions of similar climate and thus are a potential adaptation option if the capital barriers are overcome [150]. Irrigation will clearly not be helpful during times of floods.

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**Appendix 5.1: Direct Effects of Agroforestry Analysis**

**Agroforestry Range**

As mentioned in the Methods Section, agroforestry range was measured by multiplying the average height of the trees by the estimated number of trees present calculated. All analyses were also run
using an alternate measure of agroforestry involvement (height of trees*number of trees/ acres of farm, titled in graphs “Agroforestry Involvement”).

**Fuel Wood Analysis**

Fuel wood collection times were plotted using two measures of agroforestry involvement. The same general trend was observed using both measures, with less range on the y-axis using the Agroforestry Involvement measure. See Figure A5.1, fuel wood collection time plotted against the alternate agroforestry measurement.

![Figure A5.1: Agroforestry involvement plotted against time spent on fuel wood collection per week. Agroforestry involvement is measured by multiplying the average height of the trees by the number of trees present on the land.](image)

In both measures, the acreage of the farms is not taken into account for the fuel wood analysis. Although a higher tree density may reduce fuel wood collection time, it is clear from discussions with farmers that the most important factor is the total number of trees available to households on their own land. Total number of trees was not used as a proxy for the agroforestry involvement because the size of the trees is also crucial for fuel wood collection benefits. Fuel wood can only be collected from trees of certain maturity, as extensive pruning of small seedlings is detrimental to seedling health.

**Regional differences:** Breaking this analysis down across the two sub-regions of the study, the same general trend is observed in the two areas. However, there is a clustering of Middle Nyando observations in the region of the graph characterized by low tree biomass and low fuel wood collection times. This finding is likely due to the higher community land tree cover in this area, though this measure was not documented in this study. Because of the limited scope of the study, an analysis of the proximity of community forest cover was not able to be incorporated into the analysis, though this will clearly have an impact on fuel wood collection times. See Figure A5.2
Soil Erosion Analysis:

Tree biomass scale: The tree biomass scale used for this analysis took into account farm size to get an average tree density on the farm (total tree biomass/acreage of farm). The literature on the subject leads us to expect that soil erosion is affected by tree density and tree size because larger and more densely spaced trees will be more effective at holding soil [24].

Using the alternate measurement of agroforestry involvement returned almost identical results, showing the reliability of the agroforestry measure used.

Log Transformation: A log transformation of tree biomass/acre was used to redistribute the x values more evenly across the scale for further analysis. This transformation, as seen below allowed for a simpler regression to be fit to the data points. The correlation coefficient was calculated using the log transformation of the Biomass per acre variable and the standard erosion scale. A log transformation was not used on the soil erosion scale because of the high frequency of zeros in this variable. See Figure A5.3.

Comparisons across regions and groups: Summary statistics from the different regions and groups are recorded in Table A5.1. To evaluate differences in soil erosion across regions, a one sample mean-comparison test was used to compare the null hypothesis (erosion rates in Middle and Lower Nyando were equal) to the alternate hypothesis (erosion rates in Middle Nyando are lower than in Lower Nyando). The t-test gave a t statistic of -6.77 and a p value of .00001, showing there is a statistically significant difference between the two soil erosion means observed in the different regions.

In Lower Nyando, a one sample mean-comparison test was also used to compare differences across different groups. Groups were defined by the number of years they had spent interacting with ICRAF staff and using agroforestry techniques on their farms. Individuals were categorized as either having high agroforestry involvement (have engaged in agroforestry techniques for at least four years under an ICRAF project) or low to no agroforestry involvement (have engaged in agroforestry techniques for 0-2 years). The individuals that have been using agroforestry techniques for two years were grouped with the low agroforestry group because the literature review showed that trees have little to no effect until they reach at least three years of age. No similar comparison was available for the Middle Nyando group because farmers in this area had only been engaged in agroforestry for 0-2 years. The null hypothesis used in this test was that high agroforestry farmers had no statistically significant difference in soil erosion intensity than those farmers who did not
practice agroforestry. The alternate hypothesis was that agroforestry involvement reduced soil erosion. The alternate hypothesis was supported in my analysis, with a t statistic of -17.301 and a p value of <.001.

<table>
<thead>
<tr>
<th></th>
<th>Lower Nyando</th>
<th>Middle Nyando</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No to Low Agroforestry Involvement</td>
<td>High Agroforestry Involvement</td>
</tr>
<tr>
<td>Soil Erosion</td>
<td>3.41 (2.71)</td>
<td>.565 (.788)</td>
</tr>
</tbody>
</table>

Table A5.1: Summary of soil erosion for different projects across regions. Mean soil erosion values with their standard deviations in parentheses. No to low agroforestry involvement includes those farmers that have had no agroforestry training and those that have been involved in agroforestry practices for two years. High agroforestry involvement includes farmers who have been using agroforestry techniques for the last four years. No high agroforestry involvement farmers were available for analysis in the Middle Nyando region.

Figure A5.3: Tree biomass per acre compared to an alternate scale of soil erosion intensity. The soil erosion intensity scale took into account both the type and prevalence of the soil erosion observed. Excludes the most extreme outlier so the variation at low levels could be observed.
Appendix 5.2: Indirect Agroforestry Effects

<table>
<thead>
<tr>
<th>Location Effect</th>
<th>Farm Productivity (KSH)</th>
<th>Household Wealth (KSH)</th>
<th>Food Security (PCA Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower Nyando</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated</td>
<td>4,611</td>
<td>62,162</td>
<td>-.333</td>
</tr>
<tr>
<td>Control</td>
<td>3,069</td>
<td>38,410</td>
<td>-.271</td>
</tr>
<tr>
<td>Difference</td>
<td>1,542 (3,718)</td>
<td>23,752 (13,920)</td>
<td>-.062 (.226)</td>
</tr>
<tr>
<td></td>
<td>p=.678</td>
<td>p=.092</td>
<td>p=.784</td>
</tr>
<tr>
<td><strong>Middle Nyando</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated</td>
<td>16,234</td>
<td>58,918</td>
<td>.389</td>
</tr>
<tr>
<td>Control</td>
<td>14,097</td>
<td>67,341</td>
<td>.077</td>
</tr>
<tr>
<td>Difference</td>
<td>2,137 (3,426)</td>
<td>-8,423 (12,900)</td>
<td>.312 (.210)</td>
</tr>
<tr>
<td></td>
<td>p=.549</td>
<td>p=.516</td>
<td>p=.139</td>
</tr>
<tr>
<td><strong>Location Effect</strong></td>
<td>11,028 (p=.001)</td>
<td>28,931 (p=.001)</td>
<td>9.38</td>
</tr>
<tr>
<td>Adjusted R-Square</td>
<td>.4156</td>
<td>.6034</td>
<td>.1042</td>
</tr>
</tbody>
</table>

Table A5.2: Raw values of agroforestry’s effect on farm productivity, household wealth and food security. Values from linear regression models run on matched data. Food security values are reported on a Principal Component scale. For methods, see Appendix 2.4. N=116.
Works Cited


