Frailty and complexity: smallholder agriculture in semi-arid Kenya

Department of Natural Resource Sciences & McGill School of Environment
McGill University
Montreal, Quebec, Canada

March 2015
Manuscript-Based (Article-Based) Thesis

A thesis submitted to McGill University in partial fulfilment of the requirements of the degree of Master of Science in Renewable Resources (Thesis) - Environment

Table of Contents

List of Figures

List of Tables

Abstract

Agriculture, the 'backbone' of the Kenyan economy, is dominated by smallholder farmers who account for 65 per cent of total agricultural production and 51 per cent of labour force in the sector. However, with 80 per cent of land classified as arid or semi-arid land (ASAL), smallholding in Kenya exists against a backdrop of poor agro-ecological conditions. In ASALs, 86 per cent of women and children in households are classified as 'food insecure'. Climate change, characterised by increased frequency and intensity of drought in the region, inserts new layers of urgency and complexity into this already-great crisis.

Responding to these immediate food security challenges, cross-sectional household data from smallholder farmers in three Counties of semi-arid Kenya is analysed with the goal of advancing the knowledge of semi-arid smallholder agriculture and improving household food security in the region. Specifically, household agro-economic data from two Agro-Ecological Zones (AEZ), Lower Midlands 4 (LM4) and Lower Midlands 5 (LM5), in Tharaka-Nithi, Machakos and Makueni Counties is examined in the light of two themes: frailty and complexity.

Using existing literature and anecdotal evidence for hypothesis testing, I present multiple and logistic regression analyses, exposing the entrenched frailty of a smallholder agricultural system whereby even in a good season, only 52 per cent of plots break even. Three trends emerge: (i) plots in the LM4 Agro-Ecological Zone, characterised by lower mean temperature and higher annual precipitation, are more likely to break even in both good and bad seasons than farmers in the drier LM5 zone; (ii) despite anecdotal evidence provided by farmers, monocrop plots outperform mixed crop plots, offering a higher probability of breaking even in both good and bad seasons largely due to economies of scale; (iii) High Value Traditional Crops (HVTCs), notably green grams and millet, increase farmers' likelihood of breaking even in both good and bad seasons, while maize, our sample's cash crop, performs the most poorly. Reflecting on these statistical trends, data-based policy inferences - including greater HVTC adoption, 'mosaic monocropping', collective pest-management and microinsurance - are offered vis-à-vis how agricultural

policy in Kenya can better contribute to food security, drawing heavily on the FAO's climate-smart agriculture (CSA) framework.

Adopting a 'magnifying glass' approach, I then offer a theoretical (and at times humorous) analysis of one particular barrier to the greater adoption of HVTCs, bird scaring by farmers of millet and sorghum, demonstrating the inherent complexity of even the most seemingly-simple development intervention. 100 per cent of millet and sorghum farmers in the Tharaka-Nithi study area report scaring birds as a labour input, devoting on average 24-66 per cent of all labour time to this activity – a stark contrast to farmers of all other crops, almost zero per cent of which report scaring birds. However, it is farmers' behaviour with respect to birds, and not the pests themselves, that provide the greatest insight. Individually scaring birds from their land, farmers within a community continuously shift the cost of pests from one plot to the next, creating what I describe as a 'ripple effect' externality. Environment and resource economic's (ERE) prescriptions are overviewed and rendered inadequate for addressing this bird scaring tragedy. In turn, a collective action approach is proposed, incorporating farmer groups, collective planting and scaring schedules and community feeding plots.

Résumé

L'agriculture, le pilier de l'économie du Kenya, est dominée par les petits exploitants agricoles totalisant 65 pourcent de la production agricole et 51 pourcent de la main-d'œuvre du secteur. Toutefois, 80 pourcent des terres classées arides ou semi-arides exposent des conditions agro-écologiques d'appauvrissement aux petites exploitations agricoles. Dans ces terres, 86 pourcent des femmes et des enfants des ménages souffrent d'insécurité alimentaire. Les changements climatiques augmentent fréquence et intensité des sécheresses dans la région, introduisant de niveaux d'urgence et de complexité dans ces deux crises déjà importantes.

Pour y répondre, des données transversales sur les ménages des petits exploitants agricoles de trois comtés du Kenya semi-aride sont analysées avec pour objectif d'avancer la connaissance de l'agriculture des petits exploitants et d'améliorer la sécurité alimentaire dans la région. Précisément, les données des ménages agro-économiques de deux zones agro-écologiques (ZAE) : Lower Midlands 4 (LM4), Lower Midlands 5 (LM5), les comtés de Tharaka-Nithi, Machakos et Makueni sont analysés sous deux thèmes : la fragilité et la complexité.

Par la littérature existante et les témoignages anecdotiques, je présente des analyses de régressions multiples et logistiques sur la fragilité intrinsèque des systèmes des petits exploitants agricoles, qui font état du faible 52 pourcent des parcelles de terre atteignant le seuil de rentabilité. Trois tendances se tracent: (i) les lopins de terres dans la zone agro-écologique LM4 (moyenne de température faible et de précipitation élevée) obtiennent un meilleur seuil de rentabilité en haute qu'en basse saison que celles des fermiers dans la zone plus aride LM5; (ii) malgré les preuves anecdotiques des fermiers, les parcelles de terre de monocultures sont plus performantes que celles des cultures mixtes vu leur potentiel d'atteindre le seuil de rentabilité autant en haute qu'en basse saison à cause d'économies d'échelle; (iii) les cultures traditionnelles à forte valeur économique (les haricots mungo et le millet) contribuent à l'atteinte du seuil de rentabilité en haute et en basse saison, alors que le maïs, l'échantillon de culture commerciale, moins. Sur la base de ces tendances, des politiques tels que la monoculture mosaïque, la lutte intégrée aux espèces ravageuses et la micro-assurance sont offertes pour que les politiques agricoles du

Kenya contribuent à la sécurité alimentaire, s'inspirant largement du modèle «climate-smart agriculture » (CSA) de l'Organisation des Nations Unies pour l'Alimentation et l'Agriculture.

J'offre une analyse théorique (parfois humoristique) sur une barrière à l'adoption des cultures de récoltes de hautes valeurs qu'est l'effarouchement des oiseaux par les fermiers, montrant la complexité du système et ce, dans les interventions les plus anodines. 100 pourcent des fermiers de millet et de sorgho dans le rapport de Tharaka-Nithi rapportent la pratique d'effarouchement des oiseaux tel un intrant de travail témoignant y dévouer en moyenne 24 à 66 pourcent de leur temps de travail - contrastant avec les autres fermiers - y rapportant quasi-zéro pourcent. C'est dans le comportement des fermiers à l'égard des oiseaux et non pas des espèces ravageuses qu'un potentiel de contribution est décelé. Individuellement, en effrayant les oiseaux, les fermiers transfèrent le coût des espèces ravageuses d'une parcelle à l'autre, créant ainsi une externalité d'effet d'entraînement. Les prescriptions « environnement et ressources économiques » sont explorées et résolues inadaptées pour adresser la tragédie d'effarouchement des oiseaux. Une approche d'action collective est proposée incluant des groupes de fermiers, des horaires de plantations, de l'effarouchement collectif et l'alimentation communautaire des parcelles de terre.

Acknowledgements

This research was completed as part of a project titled: Enhancing Ecologically Resilient Food Security in the Semi-Arid Midlands of Kenya. This research was made possible through the Canadian International Food Security Research Fund (#106510). The Canadian International Food Security Research Fund (CIFSRF) is a program of Canada's International Development Research Centre (IDRC) undertaken with the financial support of the Government of Canada provided through Foreign Affairs, Trade and Development Canada (DFATD). I acknowledge the support of Lutta W. Muhammad and Gordon M. Hickey, Principal investigators of this CIFSRF project for the Kenya Agricultural Research Institute (KARI) and McGill University, respectively.

Data collection was conducted by Dr. Nicolas Kosoy, Professor Wellington Mulinge, Peter Maingi, John Wambua and Patrick Cortbaoui between June 2012 and July 2013. Matthew Ainsley joined this project in August, 2013, subsequent to the data collection period. All data cleaning and analysis was completed by Matthew Ainsley. The ideas for Papers I and II were formulated and developed collectively by Matthew Ainsley and Dr. Nicolas Kosoy. The initial draft of Paper I was completed in fulfilment of the SOCI 504 – Quantitative Methods course requirements (Spring, 2014); Professor Shelley Clark (course instructor and Director, Centre on Population Dynamics) provided feedback on the paper during the course period. The GIS study area maps were provided by Peter Maingi and Wellington Mulinge at the Kenya Agricultural Research Institute (KARI). Two versions of Paper I were seen by all co-authors prior to the *Land Use Policy* submission process – each author provided feedback on these drafts. Paper II was developed collectively by Matthew Ainsley and Dr. Nicolas Kosoy, with feedback on an earlier draft from Dr. Joeren van den Bergh at the Universitat Autònoma de Barcelona.

I want to extent my gratitude to all farmers who participated in this study and allowed us to enter their fields, identify their practices and customs and share their life experiences. A great thanks to Professor Mulinge, Peter Maingi, John Wambua, and Patrick Cortbaoui for their collaboration in collecting the field data. I wish to also extend my thanks to Dr. Shelley Clark in the McGill University Department of Sociology, Dr. Unai Pascual in the Department of Land Economics at Cambridge University and Dr. Joeren van den Bergh at the Universitat Autònoma de Barcelona for their insightful feedback. This thesis would not have been possible without the constant support from my supervisor, Dr. Nicolas Kosoy, an unceasing supplier of great ideas and espresso, the support you provided was beyond anything I could have expected. Finally, I would like to thank my family and friends for their constant and undying support during the process.

Contribution of Authors

Submitting this thesis under the 'manuscript option', two chapters are compiled as follows:

Paper I: Submitted to *Land Use Policy* on September 5th, 2014:

When Farmers Toss a Coin: Smallholder Agriculture and Food Security in Semi-Arid Kenya

Matthew Ainsley[a], Peter Maingi[b], Wellington Mulinge[b], Bernard Pelletier[a] & Nicolas Kosoy[a]

Data collection was conducted by Dr. Nicolas Kosoy, Professor Wellington Mulinge, Peter Maingi, John Wambua and Patrick Cortbaoui between June 2012 and July 2013. Matthew Ainsley joined this project in August, 2013, subsequent to the data collection period. All data cleaning and analysis was completed by Matthew Ainsley. The ideas for this paper were formulated and developed collectively by Matthew Ainsley and Dr. Nicolas Kosoy. The initial draft of this chapter was completed in fulfilment of the SOCI 504 – Quantitative Methods course requirements (Spring, 2014); Professor Shelley Clark (course instructor and Director, Centre on Population Dynamics) provided feedback on the paper during the course period. GIS study area maps were provided by Peter Maingi and Wellington Mulinge at the Kenya Agricultural Research Institute (KARI). Two versions of Paper I were seen by all co-authors prior to the *Land Use Policy* submission process – each author provided feedback on these drafts.

Paper II: Submitted to *Ecological Economics* on September 26th 2014:

The Tragedy of Bird Scaring

Matthew Ainsley[a] & Dr. Nicolas Kosoy[a]

[a] McGill University Department of Natural Resource Sciences
21111 Lakeshore Road,
Ste. Anne de Bellevue, Quebec, Canada

+1 514-398-7773

[b] Kenya Agricultural Research Institute (KARI)
Kaptagat Rd, Loresho Nairobi Kenya
+254 41 833619

Data collection was conducted by Dr. Nicolas Kosoy, Professor Wellington Mulinge, Peter Maingi, John Wambua and Patrick Cortbaoui between June 2012 and July 2013. Matthew Ainsley joined this project in August, 2013, subsequent to the data collection period. All data cleaning and analysis was completed by Matthew Ainsley. GIS study area maps were provided by Peter Maingi and Wellington Mulinge at the Kenya Agricultural Research Institute (KARI). The ideas for this paper were formulated and developed collectively by Matthew Ainsley and Dr. Nicolas Kosoy, with comments from Dr. Unai Pascual in the Department of Land Economics at Cambridge University and feedback on an earlier draft from Dr. Joeren van den Bergh at the Universitat Autònoma de Barcelona.

List of Acronyms and their Meaning

AEZ	Agro-Ecological Zone
ASAL	Arid or Semi-Arid Land
ASDS	Agriculture Sector Development Strategy
BAU	Business as Usual
CSA	Climate-Smart Agriculture
ERE	Environment and Resource Economics
ES	Economies of Scale
FAO	Food and Agriculture Organization of the United Nations
FFS	Farmer Field School
GDP	Gross Domestic Production
GIS	Geographic Information System
HVTC	High Value Traditional Crop
IDRC	International Development Research Centre
IFAD	The International Fund for Agricultural Development (IFAD)
IBMI	Insurances Based on Meteorological Indices
IPCC	The Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
KARI	Kenya Agricultural Research Institute
KG	Kilogram
KSH	Kenyan Shillings
LM4	Lower-Midlands 4
LM5	Lower-Midlands 5
MDG	Millennium Development Goal
MOA	Kenyan Ministry of Agriculture, Livestock and Fisheries
PAC	Problem Animal Control
PPP	Public-Private Partnerships
RFI	Reason for Intercropping
RPoL	Revenue Productivity of Labour
SCPI	Sustainable Crop Production Intensification
SD	Standard Deviation
TFPG	Total Factor Productivity Growth
UM	Upper-Midlands
UN	The United Nations
UNEP	The United Nations Environment Programme
WFP	The World Food Programme

1 Introduction

Accounting for 29.9 per cent of gross domestic product (GDP) in 2012 (The World Bank, 2013), agriculture has been described by former President Mwai Kibaki as the "backbone" of Kenya's economy (Government of the Republic of Kenya, 2010). Making up 65 per cent of national exports (Poulton and Kanyinga, 2013) and generating 60 per cent of the countries foreign exchange reserves (Odhiambo et al., 2004), agriculture is the predominant economic sector, contributing significantly to national development and, in turn, receiving high priority attention from the Kenyan national government (Ouma et al., 2001). Although large-scale producers have, in recent decades, played an increasingly-important role in the sector, agriculture in Kenya continues to be dominated by smallholders who account for 65 per cent of total agricultural production (Poulton and Kanyinga, 2013) and 51 per cent of the total labour force in the sector (Alila and Atieno, 2006); if agriculture is the 'backbone' of the Kenyan economy, smallholders should be considered the vertebrates.

Life as a farmer in Kenya, however, is fraught with challenges. While crop yields in smallholder farms have increased in recent years (Government of the Republic of Kenya, 2010), high poverty rates persist in rural areas, especially among smallholder farmers (Alila and Atieno, 2006). Nationally, 35 per cent of the population is 'food inadequate' (FAO, 2014) and 19.7 per cent of the population lives on less than $1.25 per day (UN, 2010); in arid and semi-arid lands (ASALs) these trends are more severe, where 60 per cent of the population falls below the poverty line (Romano, 2009). According to The Economist's Global Food Security Index – a "dynamic quantitative and qualitative benchmarking model, constructed from 28 unique indicators, that measures these drivers of food security across both developing and developed countries" (The Economist, 2014; p53) – Kenya ranks 80th out of 109 countries in 2014, closely behind Syria and just ahead of Tajikistan (The Economist, 2014).

1.1 Objectives

Responding to these pressing and immediate food security challenges, cross-sectional household data from smallholder farmers in three Counties of semi-arid Kenya is analysed with the overall goal of advancing the knowledge of semi-arid smallholder agriculture and improving household food security in the region. Specifically, household agro-economic data from two Agro-Ecological Zones (AEZ), Lower Midlands 4 (LM4) and Lower Midlands 5 (LM5), in Tharaka-Nithi, Machakos and Makueni Counties is examined. In total, 157 households and 483 plots are surveyed, comparing inputs and outputs during a perceived 'good season', one characterised by ample precipitation leading to a plentiful harvest and a perceived 'bad season', where minimal rainfall resulted in the prevalence of high crop failure.

Using this dataset, two manuscripts are presented in this thesis, transitioning gradually from a theme of frailty to one of complexity. The first manuscript applies multiple and logistic regression models to quantitatively capture the agro-economic state of smallholder systems in semi-arid Kenya through hypothesis testing. In particular, this chapter contains three core elements: (i) descriptive statistics and multiple regression models broadly expose the extreme frailty of smallholder systems in semi-arid Kenya, notably the inordinate (and increasing) challenge farmers face each season vis-à-vis breaking even; (ii) using regression models, I analyse which characteristics of the farm hinder or assist farmers' agricultural productivity. In particular, the impact of Agro-Ecological Zone, cropping system type and crop choice on agricultural productivity in Machakos, Makueni and Tharaka-Nithi Counties is examined; (iii) building upon this quantitative analysis, data-based policy inferences are offered for agriculture in semi-arid Kenya, drawing heavily on the Food and Agricultural Organisation's (FAO's) Climate-Smart Agriculture (CSA) framework.

Adopting a 'magnifying glass' approach to food security research, I then transition from a theme of frailty to one of complexity. Fundamentally, agriculture and food systems are complex, characterised by 'continuous change, self-organisation, interdependence and adaptation' (van Mil et al., 2014) layered across and within social, environmental, economic and biological scales (Nourish, 2014). With this second theme, I reflect on the delicate relationship between frailty and complexity, considering: what are the appropriate responses to frail agricultural systems? How can complexity be adequately managed when intervening in agricultural systems? Inevitably, exposing the frailty of an agricultural system is the 'easy bit' of food security research – the principle challenge arises when intervening in an inherently complex system. Manuscript two (section six) captures this inherent complexity, examining bird scaring by farmers of millet in sorghum in Tharaka-Nithi County as a barrier to the greater adoption of 'Climate-Smart', High Value Traditional Crops, such as millet, sorghum, cowpeas, green grams, pigeon peas and cassava. Beyond a characterisation of a system's complexity, manuscript two takes a more theoretical turn vis-à-vis micro and macroeconomics. Bird scaring by farmers is examined as an externality, and environment and resource economic's (ERE) prescriptions for externality internalisation are (at times humourously) applied and inevitably rendered futile for the case at hand. Ultimately, this externality behaviour is examined through the 'lens' of ecological economics, siding with a body of literature that describes externalities as 'cost shifting practices' and exploring collective action as an effective pest management practice among agricultural communities.

Organisationally, this thesis broadly follows van Mil et al.'s (2014) systematic approach to addressing complex problems in agriculture and food systems which comprises three stages: (i) describe the specific problem conceptually, based on observation, and offer potential intervention strategies; (ii) harvest information on each level within the complex system and; (iii) estimate the effectiveness of interventions (van Mil et al., 2014). Subsequent to this introduction, section two develops stage one by providing a brief background on smallholder agriculture and food security challenges in semi-arid Kenya. Section three overviews the study area and sampling methodology. Section four, the first manuscript-based chapter of this thesis, advances both stage one and stage two of van Mil et al.'s approach, presenting the statistics-based, CSA policy-relevant research paper. Section five transitions this thesis from a theme of fragility to one of complexity before section six, this thesis's second manuscript, provides a paper on bird scaring and economic theory to closely examine on particular intervention in line with stage three. Section seven presents the summary and extended conclusions. Finally, section eight provides the analytical appendices, including ethics approval, maps and surveys.

2 Agriculture and Food (in)Security: Describing a Frail System

Providing livelihood to approximately 80 per cent of the population (Odhiambo et al., 2004; Alila and Atieno, 2006; Poulton and Kanyinga, 2013), agriculture is the primary economic sector in Kenya (Government of the Republic of Kenya, 2010). Smallholder farmers, those with between 0.2-3ha for subsistence and commercial purposes (Government of the Republic of Kenya, 2010), dominate agriculture. There are approximately 3 million smallholder farms in Kenya, each with an average 2 hectares (Odhiambo et al., 2004), aggregately producing approximately 70 per cent of total marketed output (Odhiambo et al., 2004). In particular, smallholders cultivate more than 70 per cent of maize, 65 per cent of coffee, 50 per cent of tea and almost 100 per cent of High Value Traditional Crops (Government of the Republic of Kenya, 2010). For the purposes of this study, High Value Traditional Crops are defined as indigenous agricultural crops adapted to the extreme soil and climatic conditions of semi-arid Africa, compatible with the Agro-Ecological and socio-economic conditions of the area.

With only 9.8 per cent of land considered arable (FAO, 2014), however, Kenyan agriculture exists against a backdrop of poor, and increasingly harsh climatic conditions. According to rainfall classifications, just 20 per cent of land is 'medium-high potential' with the capacity to support a high population density, the remaining 80 per cent of land is arid or semi-arid land with the ecological capacity to support a small proportion of the population (The World Bank, 2008). Agricultural productivity and income is highest in high and medium potential zones and lowest in ASALs (Kabubo-Mariara and Karanja, 2007) where annual rainfall rates are erratic (IDRC, n.d.). The prevalence of arid and semi-arid land presents significant challenges for food security, poverty reduction and human development in Kenya (Bukania et al., 2014). According to the United Nations Food and Agricultural Organization (FAO), food security is a situation in which "… all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. Household food security is the application of this concept to the family level, with individuals within households as the focus of concern" (FAO, 2003, p. 29). Food security is multi-dimensional by definition with a number of influencing factors (FAO, IFAD and WFP, 2014). Furthermore, the FAO delineates four pillars of food security: food availability, the existence of enough food from one's own production or markets (Weingärtner, 2009); food access, which refers to the *having* of enough food, incorporating both economic and social access (Sen, 1981); food utilisation, the ability of populations to obtain sufficient nutritional intake and absorption from food (Pangaribowo et al., 2013) and; food system stability, a combination of food availability, food access and food utilization at all times without risk (Pangaribowo et al., 2013).

Food security and human development go hand in hand, with mutually reinforcing (health-nutrition and poverty-hunger) and co-determined (income-poverty) outcomes (Misselhorn et al., 2012). Agriculture is a principle driver of food (in)security and an essential component of poverty alleviation and human development (Pretty et al., 2003; Rosegrant, 2003; Odhiambo et al., 2004; Alila and Atieno, 2006; Kabubo-Mariara and Karanja, 2007; Nhemachena and Mano, 2007; Schmidhuber and Tubiello, 2007; Romano, 2009; Pretty et al., 2011; Misselhorn et al., 2012; FAO, 2013a; IFAD & UNEP, 2013; AGRA, 2014; FAO, IFAD and WFP, 2014; IFPRI, 2014). Furthermore, soil and climate resources are a determinant of household food security and human development - the performance of smallholder agriculture is determined by crop production, dependent on Kenya's endowment of soil and climate resources (Odhiambo et al., 2004; Kabubo-Mariara and Karanja, 2007). In ASALs, the prevalence of food insecurity is even greater due to poor resource endowment (Alila and Atieno, 2006), high potential evaporation and variable and unpredictable rainfall which serve to limit crop production (Nicholson, 2001). Unfavourable and worsening agro-ecological and climatic conditions in ASALs, render the food security system in semi-arid Kenya to be precariously characterised by a state of frailty - the condition of being weak or delicate (Stevenson and Lindberg, 2010). As of 2007, half of the Kenyan population lacked access to adequate food (Romano, 2009) and 16.4 per cent of Kenyan children under the age of five are underweight (FAO, 2014). Nationally, there exists an average national 'food deficit' of approximately 200 kilocalories per person per day (The World Bank, 2013) and, among the entire population, the prevalence of undernourishment is 80 per cent (The Economist, 2014) with the main concerns being vitamin A, iron and iodine deficiency disorders (Muthoni and Nyamongo, 2010). Within Machakos, Makueni and Tharaka-Nithi Counties, areas of concern to this study, 86 per cent of women and children in households are classified as 'food insecure' and stunting rates among children 6-36 months are 33.8 per cent, with the trend most prevalent in drier Agro-Ecological Zones (Bukania et al., 2014).

Each growing season, to maximise household income and dietary diversity and mitigate the crippling effects of frailty, farmers carefully select the optimal balance of cash crops, such as coffee, tea and maize, and High Value Traditional Crops. Since Kenyan independence in 1963, with changing eating habits, lack of planting materials and low interest by seed companies, production of HVTCs deteriorated (Muthoni and Nyamongo, 2010); HVTCs have suffered from a dearth of genomic and molecular-genetic resources, rendering them the 'orphan crops' of the genome revolution (Varshney et al., 2009).

In recent years, however, with the impacts of climate change reverberating through Kenya, this trend has reversed with government policy reifying HVTCs in the context of climate-smart agriculture (FAO, 2013a; Government of the Republic of Kenya, 2013; Maina et al., 2013). Climate change presents serious and complex challenges for frail agricultural systems (Howden et al., 2007; Schmidhuber and Tubiello, 2007; Verchot et al., 2007; Laukkonen et al., 2009; FAO, IFAD and WFP, 2014), in particular for smallholder farmers (Gregory et al., 2005; IPCC, 2007; Morton, 2007; IFAD & UNEP, 2013), and adds to the already-great development challenges of food security and poverty alleviation (Mendelsohn and Dinar, 1999; Jones and Thornton, 2003; IPCC, 2007; AGRA, 2014). Climate change threatens to increase the frailty of smallholder systems by increasing the risk associated with agriculture - drought cycles in Kenya have shortened in recent history from once every 5-7 years to once every 2-3 years (Romano, 2009). Kenya has seen increased frequency and intensity of drought in the past three decades (Alila and Atieno, 2006), including multiple "national drought-related food emergencies" (Smucker and Wisner, 2008, p. 190) – severe drought affected more than 4.4 million people in Kenya between 1991 and 2001 (Smucker and Wisner, 2008). Arid and semi-arid lands, already characterized by low and erratic rates of annual precipitation (IDRC, n.d.), are especially vulnerable to the impact of climate change (FAO, 2013b) and, overall, drylands in Africa will experience an increase in rainfall variability (IPCC, 2007; AGRA, 2014). To survive the impacts of climate change, smallholders in semi-arid regions will necessitate embracing climate change adaptation strategies to minimise the increased frailty threatened by our changing planet (FAO, 2013a).

In Kenya, increased adoption of High Value Traditional Crops is suggested as one such strategy (Government of the Republic of Kenya, 2010; Maina et al., 2013). In 'bad seasons', HVTCs outperform cash crops as they offer adaptation to extreme soil and climatic conditions, are known to do well in dry conditions and can survive the unpredictable weather patterns and increasing aridity (Muthoni and Nyamongo, 2010). In this context, a dependence on rain-reliant cash crops can be understood as a driver of agriculture system frailty and household food insecurity in semi-arid Kenya (Alila and Atieno, 2006). Because of these traits, drought-resilient HVTCs are preferable to water-intensive cash crops in drier areas of Kenya and are promoted by the Kenyan Government, who identify increased production of traditional commodities as an opportunity in the agricultural sector (Government of the Republic of Kenya, 2010) and a key strategy in Kenya's national climate change plan for agriculture (Maina et al., 2013). Specific crops promoted under the strategy include sweet potatoes, cassava, pigeon peas, common beans, cowpeas, green grams, dolichos, lablab, chick peas, sorghum, finger millet, pearl millet and maize (pers. comm. KARI officer). Although maize is listed in the previous category as a drought-resilient High Value Traditional Crop, this study considers maize neither drought-resilient nor traditional for the following reasons: (i) maize requires large amounts of water to achieve high production (FAO, 1991) and; (ii) maize is a relatively new crop, brought to East Africa at the beginning of the 20th century (Miracle, 1965; Hassan and Karanja, 1997).

Increased 'orphan crop'-adoption for climate change mitigation, however, is only element of agriculture policy in Kenya aimed at reducing frailty and increasing resilience. In accordance with Millennium Development Goal (MDG) 1C, "halve, between 1990 and 2015, the proportion of people who suffer from hunger" (UN, 2014; p12), the Kenyan Government's long term agriculture strategy envisions a "food-secure and prosperous nation" (The Government of the Republic of Kenya, 2010; pix). In particular, by 2015, the Government aims to reduce the number of people living below absolute poverty to less than 25 per cent and reduce food insecurity by 30 per cent (Government of the Republic of Kenya, 2010). The agriculture sector contributes to these ambitious goals through a targeted 7 per cent sector-wide growth rate to 2015, achieved via a plethora of complex system interventions including innovation, modernisation, research, market access and privatisation of state owned agricultural corporations to ultimately attain an "innovative, commercially oriented and modern agriculture" (Government of the Republic of Kenya, 2010; pxiii).

Kenyan agricultural policy broadly centres around the following key themes, as outlined by Alila and Atieno in a 2006 report for *Future Agricultures*: (i) improving Kenya's overall low agricultural productivity (notably yields per acre and high production costs) and income, largely through a transition from subsistence to commercial agriculture; (ii) promotion of irrigation and agricultural intensification in high and medium potential lands to reduce the reliance on rain-fed agriculture in the face of limited high potential land; (iii) diversification into non-traditional agricultural commodities to reduce vulnerability to shocks; (iv) poor and inadequate rural infrastructure, including market access (roads) and supply chain development; (v) encouraging private-sector-led development of the sector; (vi) environmental sustainability; (vii) inadequate and declining research in agriculture - research as a percentage of GDP remains below 10 per cent in Kenya, with the majority of funding executed by donors (Alila and Atieno, 2006).

These key policy themes are echoed by the Kenyan Government in the *Agriculture Sector Development Strategy (ASDS) 2010-2020*, a comprehensive, policy and growth-orientated review of Kenyan agriculture. In particular, the ASDS identifies a range key challenges and opportunities for the agriculture sector. Focusing on those relevant to this thesis, Table 1 identifies the key challenges and opportunities for the agriculture sector.

Official Kenyan Government Challenges and Opportunities in Agriculture Relevant to this Paper	
Challenge: Pre- and post-harvest crop losses	There exist high levels of pre and post-harvest loss to pest and disease, caused by improper handing, poor storage facilities and a lack of information (Government of the Republic of Kenya, 2010).
Challenge: Inadequate disaster preparedness and response	To address the "low preparedness, response capacity and coping mechanisms in the event of disasters such as drought, floods, fires, diseases and pests" early warning systems need strengthening (Government of the Republic of Kenya, 2010; p25).
Challenge: Poor access to agricultural information and technologies	This leads to "... low output, limited access to markets and narrow market destinations for various commodities the country is capable of producing" (Government of the Republic of Kenya, 2010; p30).
Opportunity: Potential for increasing production	In particular, inadequate effort has "... been put to increasing production of traditional commodities... Agricultural productivity can be increased in multiples through better use of unused land in traditional farming areas, and through irrigated agriculture." (Government of the Republic of Kenya, 2010; p27)
Opportunity: Potential for increasing yields	Poor agricultural productivity and output is a result of "… low adoption of appropriate technologies such as high-yielding crop varieties, inadequate application of fertilizer and manure, inefficient tillage and cultivation methods, and high cost of inputs and productive resources such as credit and irrigation infrastructure… yield of crops… are far below their optimum. Yields of maize, sugar and dairy are one-tenth of global potential. Tripling national average yields of major crop and livestock production systems in the country is easily achievable." (Government of the Republic of Kenya, 2010; p27)
Opportunity: Improving land use and crop production	"To achieve food security, initiatives will be up-scaled that involve developing appropriate technologies for the various agro-ecological zones, particularly in the ASALs where drought-resistant and new and emerging crops will be promoted alongside irrigation, water harvesting and farm forestry."

Table 1 – Official Kenyan agricultural challenges and opportunities addressed by this study. Adapted from Government of the Republic of Kenya (2010).

Directly or indirectly, this thesis has policy implications for each policy opportunity and challenge presented above and, more broadly, aims to improve household food security for smallholder farmers in semi-arid Kenya. Equipped with a broad knowledge of food security, frail smallholder systems and agriculture policy in Kenya, the following section outlines the study site and methodology.

3 Methodology & Study Overview

Data collection was conducted by Dr. Nicolas Kosoy, Professor Wellington Mulinge, Peter Maingi, John Wambua and Patrick Cortbaoui between June 2012 and July 2013 in Machakos, Makueni and Tharaka-Nithi Counties of Kenya, located in the former Eastern Province. For the project's Research Ethics Board (REB) application and Ethics Review Amendment Request, see appendix 1 and 2, respectively. Counties were selected because of their close proximity to each other, to market (Nairobi) and because both LM4 and LM5 Agro-Ecological Zones are fully represented. An Agro-Ecological Zone is a "… land resources mapping unit, defined in terms of climatic, landform and soils, land cover and having specific potentials and constraints for land use" (FAO, n.d.). Both LM4 and LM5 are characterized by upland, low fertility soils, requiring an intensive supply of manure and fertilizer each season. Furthermore, both AEZs have biannual mode of rainfall, namely short rains (October, November and December) and long rains (March, April and May), with the LM4 zone receiving a higher annual mean rainfall (Ralph et al., 2006). Within each county, road-accessible villages located exclusively in either LM4 of LM5 were selected to allow for a pairwise comparison. For Agro-Ecological Zone maps of Machakos, Makueni and Tharaka-Nithi Counties, see appendices 3 and 4.

A representative number of households in each village were randomly sampled, equivalent to 30 per cent of the entire population, leading to a total of 157 households surveyed across all three Counties. This small sample size and sampling intensity limit the external validity of this dissertation's findings. In particular, the population of each county is considerably larger than that of each village sampled and a variety of agro-ecological conditions exist within the region, rendering the results applicable specifically to the study area. However, using existing literature and government policies, these context-specific results are placed within the region's larger food security and agriculture policy discussion. Table 2 overviews the general study site characteristics. Figure 1 provides a map of the study area.

	Machakos	*Makueni*	*Tharaka-Nithi*
Population	1,098,584	884,527	365,330
Population Density (people/KM^2)	177	100.4	138
Population Composition (Male-Female)	49.4-50.6%	49-51%	48-52%
LM4 Villages Sampled	Hathara, Kyethivo, Windala	Kyamusoi, Makutano, Muambani	Gantundu, Kamathuri, Kanyange
LM5 Villages Sampled	Hathara, Itunduimuni, Kilaatu, Miondoni	Kyamusoi, Makutano	Kaibugi, Karikithi, Kiiriga
Number of Households Surveyed	38	43	76

Table 2 – General study site characteristics (KARI, n.d., n.d., n.d.).

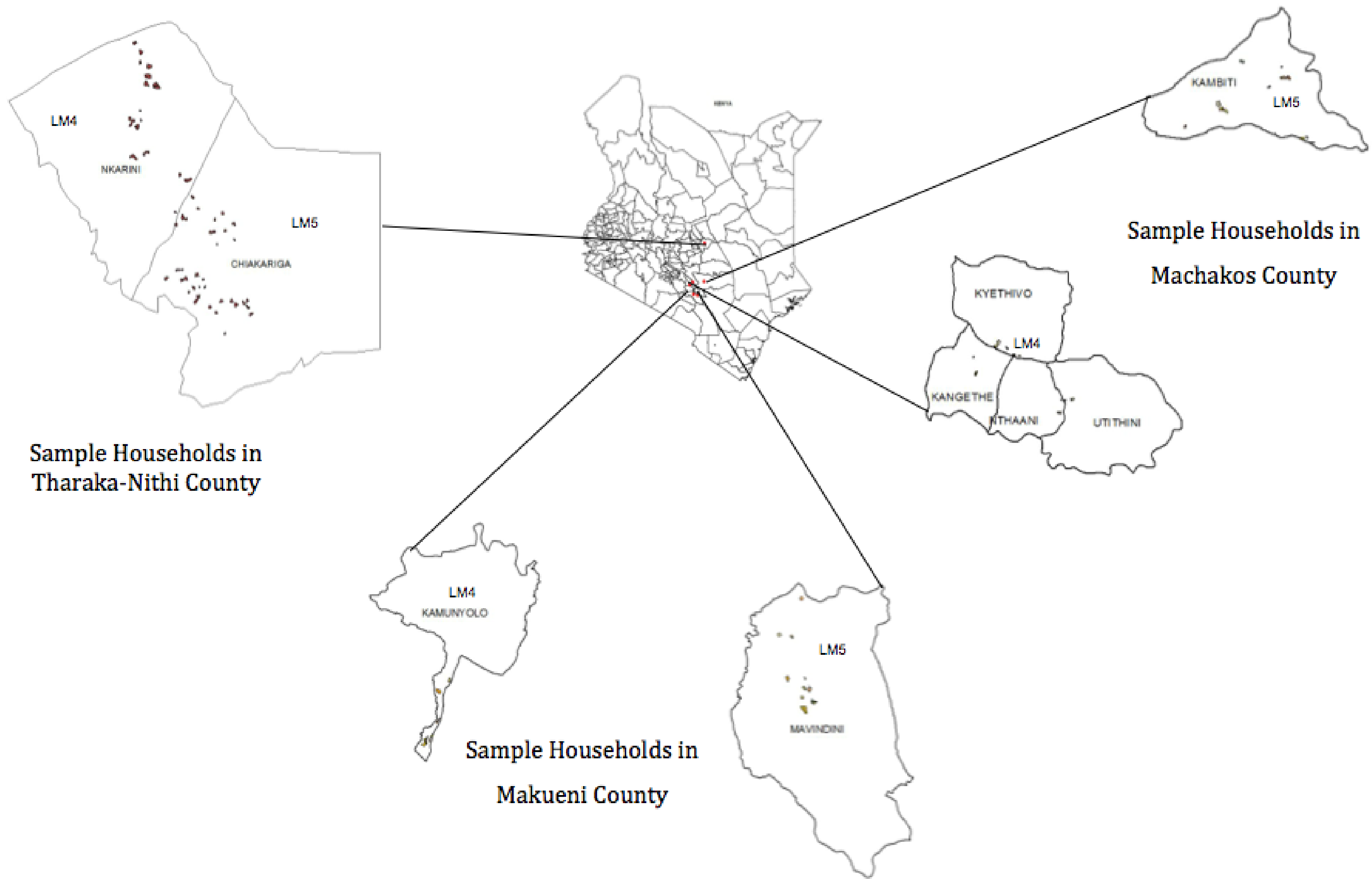


Figure 1 - Selected study site locations and villages within Agro-Ecological Zones LM4 and LM5.

Kin related households were selectively eliminated to avoid pseudo-replications of farming practices, allowing for independence among populations sampled (Hurlbert, 1984). The focus of analysis is at the plot level, understanding that smallholders cultivate multiple plots of different cropping systems simultaneously within the farm. Zero commensurability among plots is assumed - each plot is treated as an individual production unit. A map of each household was generated using mobile phones *Sports Tracker* GPS technology (see Figure 2). Maps were then exported to Google Earth and farmers were shown their plots on the spot, placing plots in the broader landscape. Any inconsistencies between drawn plots and farmers' understanding of plot boundaries were addressed *in situ*. Google Earth maps were then transferred to ARC GIS for digitization, converting Google KML maps to SHAPE maps and then to ARC VIEW for matching survey information and Geo-referenced plots. Surveys were administered based on farmers' consent to participate securing an ethical engagement with local communities.

Figure 2 - Farmers' plots are mapped using *Sports Tracker* GPS technology.

Meetings with household members were conducted in three stages:

1. Drawing of the *shamba* (Kiswahili = farm or plot of land) with the farmer, focusing on the placement of each cropping system in his or her farm.
2. Assessing labour activities (19 total) associated with the cropping systems. Farmers self-reported labour inputs (in terms of man-days) per plot in both a 'good season', one characterised by ample precipitation leading to a plentiful harvest and a 'bad season', where minimal rainfall resulted in the prevalence of high crop failure.
3. Collecting information on cost of inputs for production (18 total) needed for each cropping system. 'Good' and 'bad' season cost data was once more collected using the same parameters.

Appendix 5 provides the survey administered to farmers.

Figure 3 demonstrates Dr. Nicolas Kosoy, Professor Mulinge and Patrick Cortbaoui engaging with farmers during the study.

Figure 3 – Professors Mulinge and Kosoy and a student engage with farmers during the study.

Table 3 provides an overview of the study objectives, methods used and data derived.

General Objective	Specific Objectives	Methods	Data
Identify obstacles that hinder the attainment of food security at the household level and barriers to the greater adoption of HVTCs.	To broadly capture the main cropping systems for smallholder farmers in the region by recording what is cultivated within eighteen villages in Machakos, Makunei and Tharaka-Nithi Counties.	Participatory drawing of plots.	Listing of cropping systems.
	To describe the main activities and time spent per cropping system previously identified.	Surveys identifying all activities associated with growing the different cropping systems.	Time budgeting of cropping systems.
	To estimate the rent derived out of these cropping systems.	Surveys assessing cost and benefit of the cropping systems in monetary terms.	Monetary costs of input of production and monetary benefits per cropping system

Table 3 - Summary of study objectives.

Table 4 details all variables surveyed during the study, where a * indicates that data was derived from farmers' own records.

Descriptive Variables	Labour Input Variables (man-day)*	Cost Input Variables (KSH)*	Output Variables*
Agro-Ecological Zone	Bush Clearing	Seeds: Improved	Production - Good Season (Kg/acre)
Village	Burning	Seeds: Local	Production - Bad Season (Kg/acre)
County	Cleaning Leftovers	Field Pesticides: Natural	Selling Price - Good Season (KSH/kg)
Shamba (*Kiswahili* = farm or plot of land) Code	Soil Conservation	Field Pesticides: Synthetic	Selling Price - Bad Season (KSH/kg)
Crop	Manuring	Storage Pesticides: Natural	
Plot Acreage	Ploughing	Storage Pesticides: Synthetic	
	Fertilizing	Organic Fertilizers: Manure	
	Planting	Organic Fertilizers: Compost	
	First Weeding	Irrigation: Treated	
	Second Weeding	Irrigation: Not treated	
	Third Weeding	Inorganic Fertilizers: Phosphate	
	First Spraying	Inorganic Fertilizers: Nitrogen	
	Second Spraying	Labour: Household member	
	Bird Scaring	Labour: Household not member	
	Harvesting	Technology: Pre-Harvest	
	Drying	Technology: Post-Harvest	
	Threshing	Distance to Market: With Transport	
	Storage	Distance to Market: Without Transport	
		Cess	

Table 4 - List of all variables surveyed during the study.

Cost and labour input variables were normalized by acre *post festum* during the three-month data cleaning and analysis phase (Microsoft Excel and STATA). Similarly, for each plot, the following variables for analysis were also calculated during this phase:

Total Revenue (KSH/acre) = Production * Selling Price

Cost Intensity (KSH/acre) = ∑Cost Inputs / Acreage

Note: as detailed in Table 4, the opportunity cost of labour is included as a cost input

Labour Intensity (man-day/acre) = ∑Labour Inputs / Acreage

Economic Rent (KSH/acre) = Total Revenue – Cost Intensity

Labour Productivity (KG/man-day) = Production / Labour Intensity[1]

Revenue Productivity of Labour (RPoL) (KSH/man-day) = Total Revenue / Labour Intensity

Overall, this study design can be described as a pairwise comparison using semi-stratified sampling techniques. Stratified sampling divides a population into a set of distinct subpopulations, so that units within the population are homogenous – this approach allows user to obtain subpopulation specific and population-wide estimates (Jensen and Bourgeron, 2001).

[1] Labour productivity across different crops cannot be compared for this would incur in an analytical error - different crops have different yield values. To accurately contrast output per unit of labour input across different crops, we analyse 'revenue productivity of labour' (RPoL). Calculating both labour productivity and labour revenue, we present the importance of household labour from a: 1) nutritional, material perspective, examining each day of labour devoted to agriculture in terms of KG produced and; 2) a monetary perspective, understanding productivity more in terms of Kenyan Shilling (KSH) output.

4 When Farmers Toss a Coin: Smallholder Agriculture in Semi-Arid Kenya

A version of this chapter was submitted to *Land Use Policy* on 5th September 2014.

Matthew Ainsley[a], Peter Maingi[b], Wellington Mulinge[b], Bernard Pelletier[a] &
Nicolas Kosoy[a,*]

[a] McGill University Department of Natural Resource Sciences
21111 Lakeshore Road,
Ste. Anne de Bellevue, Quebec, Canada
+1 514-398-7773

[b] Kenya Agricultural Research Institute (KARI)
Kaptagat Rd, Loresho Nairobi Kenya
+254 41 833619

matthew.ainsley@mail.mcgill.ca
peterm.maingi1951@yahoo.com
wellington.mulinge@kari.org
bernard.pelletier@mcgill.ca
*Corresponding author: nicolas.kosoy@mcgill.ca

4.1 Introduction

This manuscript uses regression analysis to examine smallholder household agriculture in eighteen villages of three Counties of semi-arid Kenya with the goal of improving household food security in the region, ultimately offering data-based policy inferences for smallholder agriculture in the region, responding to a climate-smart agriculture (CSA) framework (FAO, 2013a; Government of the Republic of Kenya, 2013; AGRA, 2014). In line with these objectives, I adhere to the first and second steps of van Mil et al.'s (2014) systematic approach to addressing complex problems in agriculture and food systems: (i) describe the specific problem conceptually, based on observation and statistics, and offer potential intervention strategies and; (ii) harvest information on each level within the complex system (van Mil et al., 2014). Specifically, three research questions are tested through a combination of multiple and logistic (logit) regression: What is the impact of Agro-Ecological Zone on household agricultural production in the study area of semi-arid Kenya? What is the impact of cropping system - monocrop or mixed crop plot - on household agricultural production in the study area of semi-arid Kenya? Finally, at the household level, what are the top performing crops in the study area of LM4 and LM5 AEZs, across both good and bad seasons?

The following manuscript is divided into six sections: section 4.2 details each research question and corresponding hypothesis in the context of existing academic and professional literature; section 4.3 overviews the statistical models applied; section 4.4 presents the results of the study; section 4.5 discusses the results in the light of their policy relevance, overviewing and applying a climate-smart agriculture framework for semi-arid Kenya;

4.2 Research Questions and Hypotheses

Studying the impact of Agro-Ecological Zone on agriculture, I aim to further understand the immediate, direct link between land, agriculture and livelihood. The AEZ approach has been developed by the FAO over the past three decades as a method of dividing heterogeneous landscapes into homogenous zones (Kurukulasuriya and Mendelsohn, 2008), measuring crop productivity, differentiating risk and informing farmers and policymakers (Ralph et al., 2006). In Kenya, AEZs are classified according to two characteristics: temperature belts, defined according to the maximum temperature limits for principle crops, and; main zones (similar to Braun's climatic zones in the Precipitation/Evaporation Index) based on the probability of meeting temperature and water requirements for leading crops (Ralph et al., 2006). Table 5 outlines the Agro-Ecological Zones of the tropics in Kenya.

Agro-Ecological Zones of the Tropics[1] in Kenya

Belts of Z / Main Zones	0 (perhumid)	1 (humid)[2]	2 (subhumid)[2]	3 (semi-humid)[2]	4 (transitional)[2]	5 (semi-arid)[2]	6 (arid)[2]	7 (perarid)[2]
TA **Tropical Alpine Zones** Annual Mean: 2-10°c	Glacier / Mountain Swamps	II Cattle Sheep Zone			II Sheep Zone			*High Altitude Deserts
UH **Upper Highland Zones** Annual mean 10-15°c Seasons night frosts	Forest Zones	Sheep-Dairy Zone	Pyrethrum-Wheat Zone	Wheat-Barley Zone	U. Highland Ranching Zone	*UH Nomadism Zone[5]		
LH **Lower Highland Zones** Annual mean 15-18°c M. min 8-11°c norm. no frost		Tea-Dairy Zone	Wheal/Maize-Pyrethrum-Zone[3]	Wheat/Maize-Barlye-Zone[3]	Cattle-Sheep-Barley-Zone	I. Highland Ranching Zone	*L. H. Nomadism Zone[5]	
UM **Upper Midland Zones** Ann. Mean 18-21°c M. min 11-14°c		Coffee-Tea Zone	Main Coffee-Zone	Maize and Marginal Coffee Zone[4]	Maize-Sunflower Zone[4]	Livestock-Sorghum Zone	U. Midland Ranching Zone	U Midland Nomadism Zone[5]
LM **Lower Midland Zones** Ann. Mean 21-24°c M min >14°c		L. Midland Sugarcane Zone	Marginal Sugarcane Zone	Maize and Cotton Zone[4]	Maize and Marginal Cotton Zone[6]	L Midland Livestock-Millet Zone	L. Midland Ranching Zone	L. Midland Nomadism Zone[5]
L Lowland Zones **Il Inner Lowland Zones** Ann. Mean >24°c Mean max <31°c	*	*Rice-Taro Zone	*Inner Lowland Rice-Sugarcane Zone	*Inner Lowland Cotton Zone	*Sorghum-Groundnut Zone	Inner Lowland Livestock-Millet Zone	Lowland Ranching Zone	Inner Lowland Nomadism Zone[5]
CL **Coastal Lowland Zone[6]** Ann. Mean >24°c Mean max <31°c	*	*Cocoa-Oilpalm Zone	Coastal Lowland Rice-Sugarcane Zone	Coconut-Cassava Zone	Marginal Cotton and Cashewnut-Cass Zone-Cass Zone[7]	Coastal Lowland Livestock-Millet Zone	Coastal Lowland Ranching Zone	Coastal Lowland Nomadism Zone[5]

1) Inner Tropics, different zonation towards the margins. The T for Tropical is left out of the thermal belts of zones (except TA) because it is only necessary if other climates occur in the same country. The names of potentially leading crops were used to indicate the zones. Of course these crops can be grown in some other zones, but they are then normally less profitable.

2) No strict thresholds due to the rainfall requirements of the leading crops of the main zones resp. different distribution of rainfall during the year.

3) Wheat or maize depending on farm scale, topography, a.o.

4) Maize is a good cash crop here, but maize also in LH1, UM 1-2, LM 1-2, L 1-4 and partly in the better subzones of LM5 and L5.

5) Nomadism, semi-nomadism and other forms of shifting grazing.

6) An exception because of the vicinity of cold currents are the tropical cold Coastal Lowlands in cCL in Peru and Namibia. Ann mean there between 18 and 24°c.

7) In unimodal rainfall areas growing periods may be already too short for cotton.

* Not occouring in Kenya.

Table 5 - Agro-Ecological Zones of the Tropics in Kenya (Source: Ralph et al., 2006).

This study examines two principle AEZs of Kenya, Lower Midlands 4 (LM4) and Lower Midlands 5 (LM5). Table 6 describes the key characteristics of each.

	Lower Midlands 4 (LM4)	Lower Midlands 5 (LM5)
Altitude (m)	760-1300	750-1500
Annual Mean Temperature (°C)	21-23.5	21-24
Annual Mean Rainfall (mm)	800-1050	580-800

Table 6 - Characteristics of Lower Midlands 4 (LM4) and Lower Midlands 5 (LM5) (Ralph et al., 2006).

As Tables 5 and 6 illustrate, LM4 is characterised by a marginally lower mean temperature and greater annual mean precipitation. In semi-arid Kenya, with populations entirely dependent on rainfall (Oram, 1985; Hansen, 2002), it is hypothesised that farmers in the Lower Midlands 4 Agro-Ecological Zone are situated within favourable climatic conditions for agricultural production in both good and bad seasons. Specifically, it is hypothesised that farmers in the LM4 zone are more likely to break even, experience higher economic rent and revenue productivity of labour (RPoL) along with lower cost and labour intensities than farmers in the LM5 zone.

Various AEZ and climate studies support this hypothesis. Odhiambo et al. (2004), for example, uses econometric analysis to demonstrate that rainfall is a determinant of total factor productivity growth (TFPG) in Kenya (Odhiambo et al., 2004). Furthermore, many rainfall, climate and agriculture studies apply a Ricardian Model. Developed by Mendelsohn, Nordhaus and Shaw (1994), The Ricardian Model is a cross-sectional technique that regresses net revenues on independent variables, explaining variation in land value per hectare over climatic zones (Mendelsohn et al., 1994). This model assumes that each farmer maximises his or her income subject to the farm's exogenous conditions (Seo and Mendelsohn, 2008a). Specifically, Seo and Mendelsohn (2008, p70) state: "If the farmer chooses the crop or livestock that provides the highest net income and chooses each endogenous input in order to maximise net income, the resulting chosen net income will be a function of just the exogenous variables…" Employing a Ricardian Model, various studies show the sensitivity of land value per hectare of cropland, crop net revenue and livestock net revenue to seasonal precipitation and temperature – with land and climatic variables, exogenous to the farmer, determinant of land value and production (Mendelsohn et al., 1994; Dinar et al., 1998; Mendelsohn, 2001; Mendelsohn et al., 2001; Mendelsohn and Dinar, 2003; Mendelsohn et al., 2004; Kurukulasuriya et al., 2006; Nhemachena and Mano, 2007; Seo and Mendelsohn, 2007; Kurukulasuriya and Mendelsohn, 2008; Seo and Mendelsohn, 2008a, 2008b).

Moving beyond the AEZ analysis, more micro-level characteristics of smallholder farms are examined, studying the impact of chosen cropping system, mixed crop plot or monocrop plot, on agricultural production. For the purpose of this study, a monocrop plot is defined as a small sub-lot dedicated to the cultivation of a single crop, understanding that farmers may have multiple plots in their land. Furthermore, a mixed crop plot is defined as one in which two or more crops are cultivated simultaneously within the same plot (FAO, n.d.). During the data-gathering phase of the study, farmers provided strong anecdotal evidence of the importance of mixed crop plots to their livelihood, asserting that mixing crops together inside the same area of a plantation yielded two key benefits: optimisation of land use and maximisation of variety among yield. Various studies detail the importance of mixed crop plots in traditional farming systems in the tropics (Aiyer, 1950; Mathur, 1963; Norman, 1967; Collinson, 1983). Fordham (1983), for example, finds mixed cropping to be the most widely used cropping system by smallholder farmers in tropical Africa (Fordham, 1983). Mixed cropping increases infiltration of carbon into the soil and reduces cumulative soil erosion compared to monoculture fields (Thierfelder et al., 2012). Additionally, mixed crop plots reduce the likelihood of weed infestation and are more productive and profitable than sole crop plots (Midega et al., 2014) - this trend is particularly apparent when maize is intercropped with legumes (Waddington et al., 2007; Mucheru-Muna et al., 2010; Rusinamhodzi et al., 2012). Mixed cropping reduces peak labour demand and plays an important role as 'insurance' against risk (Jodha, 1980). Jodha (1980: p440) summarises the importance of mixed cropping, describing the technique as "…. an important feature of traditional farming systems. It embodies the traditional wisdom of the farmer as it relates to his crop decisions. The available documented evidence shows [its] superiority … in terms of gross returns per hectare as well as per man day used during the labour scarce period of the crop season".

In Kenya, this analysis is supported by Songa et al. (2002) who found more than 50 per cent of maize farmers across six Agro-Ecological Zones grew maize in association with other crops, with 87 per cent and 73 per cent of all households in LM4 and LM5, respectively, reporting the practice (Songa et al., 2002). The study asked farmers for the reasons for intercropping (RFI), 100 per cent of which described 'meeting dietary needs' (Songa et al., 2002). Additionally, in LM4 and LM5 zones, 100 per cent of households reported 'inherited practice' as a RFI, reinforcing the 'traditional wisdom' aspect of mixed cropping previously outlined by Jodha (1980). Table 7 outlines maize farmers' reasons for intercropping across Agro-Ecological Zones relevant to this study.

			Reasons why farmers intercrop maize with other crops			
			Mean percentage of farmers			
AEZ	**Percentage of Farmers Intercropping Maize**	**Association Crops**	**Food Security**	**Meet Dietary Needs**	**Provide Food and Cash**	**Inherited Practice**
LM4	86.7	beans, pigeon peas, cowpeas, green grams, sorghum	46.7	100	66.7	100
LM5	73.3	beans, pigeon peas, cowpeas, green grams, millet	73.3	100	13.3	100

Table 7 - Reasons for intercropping (RFI) in LM4 and LM5 Agro-Ecological Zones (Songa et al., 2002).

Based on the above, it is hypothesised that mixed crop plots are the optimal cropping system for farmers in semi-arid Kenya, regardless of Agro-Ecological Zone, in both good and bad seasons. Specifically, it is hypothesised that mixed crop plots will achieve a higher economic rent and RPoL, are more likely to break even and experience lower cost and labour intensities compared to monocrop plots.

The final level of analysis undertaken by this study looks closer still at farmers' agricultural decisions, examining the performance of specific, popular crops within monocrop plots. Examining monocrop plots in isolation allows us to more concretely and precisely determine which crops perform best under what conditions. While no specific hypothesis is herein stated, the performance of drought-resilient, High Value Traditional Crops are of particular interest for the drought-resilient reasons previously outlined. Examining how certain crops perform during both good and bad seasons under various agro-ecological conditions, I aim to understand which crops under what conditions increase the probability of farmers achieving food security.

4.3 Calculations

Two statistical models were developed to answer the three research questions: multiple regression and logistic (logit) regression. The first model applied a multiple regression model to examine the impact of cropping system type and Agro-Ecological Zone on cost and labour intensity, production, economic rent, labour productivity and revenue productivity of labour. With binary independent variables and continuous dependent variables, a multiple regression model was the best fit for the data, estimating a single outcome with multiple predictor variables (Stock, 2011). Equation 1 presents the form of the multiple regression model:

Equation 1: $$Y = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots \beta_k X_{ki} + e_i$$

Where: *i* is the observation; *k* the number of independent variables; *e* the error term and; *k+1* the number of parameters to be estimated and; *Y* the outcome variable. This model was run ten different times for various outcomes. Throughout each test, the effect of acreage was controlled for - across all models, acreage as an independent variable was a significant, positive predictor of the outcome variable, even though the indicators are normalised by acre. The significant effect of acreage was made clear by performing a F-test on acreage and the relevant variables to find their joint significance.

The following ten regression models were performed in the statistical software STATA, applying heteroskedasticity-robust standard errors throughout:

Regression 1: $$Y_{Cost\ Intensity} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$$

Regression 2: $$Y_{Labour\ Intensity} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$$

Regression 3: $$Y_{Production-Good\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$$

$Regression\ 4:\quad Y_{Production-Bad\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

$Regression\ 5:\quad Y_{Economic\ Rent-Good\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

$Regression\ 6:\quad Y_{Economic\ Rent-Bad\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

$Regression\ 7:\quad Y_{Labour\ Productivity\ -Good\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

$Regression\ 8:\quad Y_{Labour\ Productivity\ -Bad\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

$Regression\ 9:\quad Y_{Revenue\ Productivity\ of\ Labour\ -\ Good\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

$Regression\ 10:\quad Y_{Revenue\ Productivity\ of\ Labour\ -\ Bad\ Season} = \beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i + e_i$

This multiple regression model provides insight into the first and second research questions - namely the impact of Agro-Ecological Zone and cropping system on household agricultural production in the region – describing the influence of each on cost and labour intensity, production, economic rent, labour productivity and RPoL.

The second model applied a logistic regression to examine the relationship between AEZ, cropping system, popular monocrops and the ability of farmers to 'break even' in both good and bad seasons. A logit regression is a nonlinear regression model for binary dependent variables, modelled using the cumulative logistic distribution function (Stock, 2011). With a binary dependent variable and multiple binary independent variables, a probability-oriented logistic regression model was deemed ideal, allowing us to see the probability of breaking even in both good and bad seasons given a set of conditions. To achieve this, a dummy variable was created with a value of one (1) if economic rent was positive (+) in a season, and zero (0) if economic rent was negative (-) in a season. Examining the impact of AEZ, cropping system and specific monocrops, the logit regression with 'break even' contributes to the answering of all three research questions. 'Break even', however, should not be understood as a proxy for food security attainment but as a metric for the relative success of certain agricultural conditions in the region.

Equation 2 presents the logit model form:

$$Equation\ 2:\quad Pr(Y=1|X)=F(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_{3i} + \ldots \beta_k X_k) = F(z)$$

For the same reasons outlined previously, the effect of acreage was controlled for. This logistic regression model was run twice, with each model run separately for 'good' and 'bad' season as follows:

Model 1: $Pr(\text{Break Even } \textbf{Good Season}=1|AEZ, CroppingSystem, Acreage) = F(\beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i) = F(z)$

$Pr(\text{Break Even } \textbf{Bad Season}=1| AEZ, CroppingSystem, Acreage) = F(\beta_0 + \beta_1 AEZ_i + \beta_2 CroppingSystem_i + \beta_3 Acreage_i) = F(z)$

Model 2: $Pr(\text{Break Even } \textbf{Good Season}=1|AEZ, Cowpeas, Green Grams, Maize, Millet, Pigeon Peas, Sorghum, Acreage) = F(\beta_0 + \beta_1 AEZ_i + \beta_2 Cowpeas_i + \beta_3 Greengrams + B_4 Maize + \beta_5 Millet + \beta_6 PigeonPea + \beta_7 Sorghum_i + \beta_8 Acreage_i) = F(z)$

$Pr(\text{Break Even } \textbf{Bad Season}=1|AEZ, Cowpeas, Green Grams, Maize, Millet, Pigeon Peas, Sorghum, Acreage) = F(\beta_0 + \beta_1 AEZ_i + \beta_2 Cowpeas_i + \beta_3 Greengrams + B_4 Maize + \beta_5 Millet + \beta_6 PigeonPea + \beta_7 Sorghum_i + \beta_8 Acreage_i) = F(z)$

In the second model, the individual variable 'cropping system' was dropped to avoid perfect multicolinearity. LM5 'pigeon peas' was additionally dropped from the regression because only one household was growing this particular crop as a monocrop.

Using the logit model output, STATA's *prvalue* function was used to calculate the predicted probability of economic rent break even in good and bad seasons for each AEZ, cropping system and monocrop. Predicted probabilities are calculated as follows:

Equation3: $Pr(\text{Break Even} = e^z / 1+ e^z$, where $z = \beta_0 + \beta_1 X_1 \ldots + \beta_k X_k$

Equation 4: $Pr(\text{Not Break Even}) = 1- Pr(\text{Break Even})$

Finally, looking closer still at each predicted probability, the probability of economic rent break even in both good and bad seasons, in neither season, or in either season for each AEZ, cropping system and individual monocrop is calculated. Equations 5-7 details the calculation of each probability:

*Equation 5: Pr(Break Even in Both Good and Bad Seasons) = Pr(Break Even Good Season)*Pr(Break Even Bad Season)*

*Equation 6: Pr(Break Even in Neither Good nor Bad Season) = Pr(Not Break Even Good Season)*Pr(Not Break Even Bad Season)*

Equation 7: Pr(Break Even in Either Good or Bad Season) = [Pr(Break Even Good Season)+Pr(Break Even Bad Season)]-[Pr(Break Even in Both Good and Bad Season)]

4.4 Results

4.4.1 General Trends

Ten per cent of the data - outliers containing unique combinations of crops that were only grown on one plot by one farmer - were dropped from the study during the data-cleaning phase. Eleven additional observations were dropped from the dataset due to missing or incomplete variables. Following these drops, 153 households remained. Figure 4 shows the frequency distribution of crops across all three Counties by Agro-Ecological Zone.

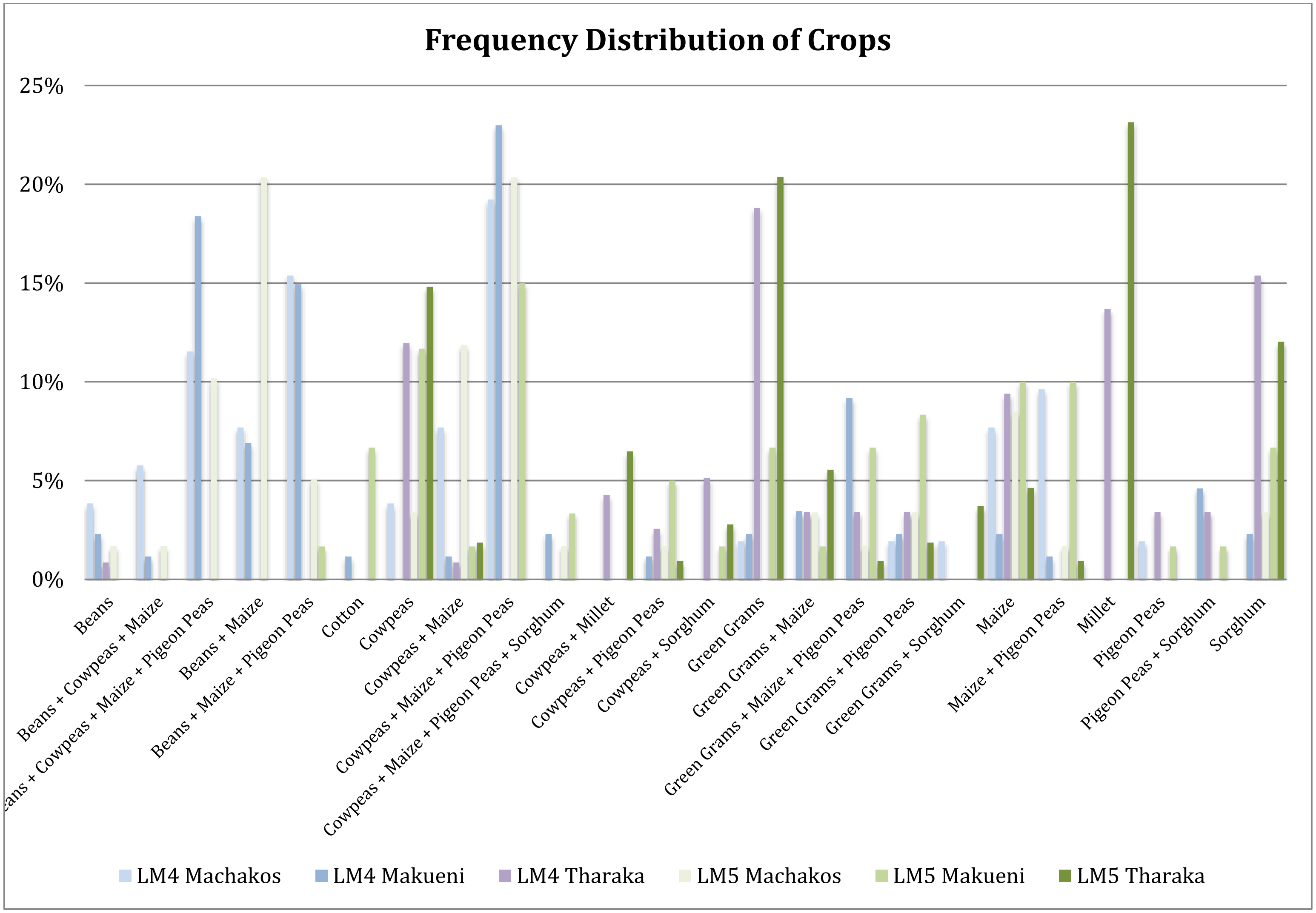


Figure 4 - Frequency distribution of crops across Machakos, Makueni and Tharaka Counties.

Table 8 details the descriptive statistics drawn from the study.

	Lower Midlands 4 (LM4)	Lower Midlands 5 (LM5)
Number of Households	87	66
Number of Plots	256	227
Mean Plots per Household	2.94	3.44
Mean Plot Size (acre)	1.26 (SD: 1.15)	1.04 (SD: 0.99)
% Mixed Crop Plots, % Monocrop Plots	59%, 41%	45.46%, 51.54%
Mean Production - Good Season (KG/acre)	675.33 (SD: 473.39)	542 (SD: 325.88)
Mean Production – Bad Season (KG/acre)	138.71 (SD: 193.43)	114.68 (SD: 126.03)
Mean Cost Intensity (KSH/acre)	20610.24 (SD: 25600.32)	22278.73 (SD: 21160.67)
Mean Labour Intensity (man-day/acre)	92.73 (SD: 97.38)	100.52 (SD: 111.08)
Mean Economic Rent - Good Season (KSH/Acre)	-92.49 (SD: 27069.77)	-4579.43 (SD: 21844.93)
Mean Economic Rent - Bad Season (KSH/Acre)	-12385.75 (SD: 26892.89)	-15598.88 (SD: 22294.04)
Mean Labour Productivity - Good Season (KG/man-day)	15.48 (SD: 30.53)	8.91 (SD: 8.34)
Mean Labour Productivity - Bad Season (KG/man-day)	3.36 (SD: 9.66)	1.94 (SD: 3.02)
Mean RPoL - Good Season (KSH/man-day)	522.07 (SD: 1184.57)	287.63 (SD: 227.23)
Mean RPoL - Bad Season (KSH/man-day)	227.11 (SD: 803.72)	113.00 (SD: 188.99)

Table 8 - Descriptive statistics of the study.

More households (32%) are represented in the LM4 zone than in LM5. This difference is partially offset by the total number of plots in each AEZ – with 3.44 plots per household, LM5 farmers have more plots than farmers in LM4. This discrepancy means that despite significantly fewer households surveyed in the LM4 zone, there are only 12 per cent fewer plots represented. With reference to cropping system, there exists a relatively even split of mixed and monocrop plots across both zones. Critically, across both AEZs, mean economic rent is negative in both good and bad seasons, highlighting the frail nature of food security in Kenyan ASALs.

Table 9 presents the multiple regression results.

*** = α<0.01 ** = α<0.05 * = α<0.1	**Multiple Regression Output**			
	Agro-Ecological Zone	**Plot Type**	**Acreage**	***n***
Cost Intensity (KSH/acre)	1002.60 (1957.44)	-12478.05 (1947.84)***	-8715.81 (1125.47) ***	473
Labour Intensity (man-day/acre)	4.83 (0.03)	-48.79 (9.07) ***	-35.75 (4.80) ***	473
Production - Good Season (KG/acre)	-120.88 (34.60) ***	-264.82 (35.07) ***	-63.70 (18.86) ***	473
Production - Bad Season (KG/acre)	-19.32 (14.51)	-65.76 (14.92) ***	-8.45 (7.40)	473
Economic Rent - Good Season (KSH/acre)	-3485.53 (2185.41)	5773.30 (2168.01) ***	7196.68 (1082.59) ***	473
Economic Rent - Bad Season (KSH/acre)	-2349.32 (2123.45)	9597.91 (2110.61)***	8308.68 (1048.18) ***	473
Labour Productivity - Good Season (KG/man-day)	-4.43 (1.92) ***	-1.06 (1.19)	9.30 (4.84) *	473
Labour Productivity - Bad Season (KG/man-day)	-0.76 (0.42)*	-0.34 (0.44)	2.84 (1.48) *	473
RPoL - Good Season (KSH/man-day)	-161.43 (46.33) ***	46.32 (3.33)	354.24 (192.78) *	473
RPoL - Bad Season KSH/man-day)	-68.73 (31.55)**	-6.61 (30.01)	210.12 (133.37)	473

Table 9 – Multiple regression results, where LM4=0, LM5=1, Mixed Crop Plot=0 Monocrop Plot=1.

In almost all regressions, acreage was a significant predictor of agricultural productivity. A 1-acre increase in farm size increases economic rent significantly in both good and bad seasons and has a strong positive effect on both cost and labour intensity. While farmers with larger plots may have higher economic rent overall, this trend is not consistent with production - a 1-acre increase in farm size actually decreases yield per acre.

The coefficient on Agro-Ecological Zone yielded mixed but favourable results. Half of the surveyed coefficients displayed significance, including production in a good season and labour productivity and RPoL in both seasons. Among these significant variables, the direction of the coefficients align with the hypothesis of the first research question – farmers in LM5 zone, characterised by drier climatic conditions, have a lower overall agricultural productivity.

There is a clear relationship between 'cropping system' and agricultural production as evidenced in six out of ten significant results. The direction of the coefficients, however, fails to support the second hypothesis of this paper that mixed crop plots are the optimal plot-type for farmers in the region, regardless of AEZ or season. While production (yield) in mixed crop plots is between 65.76 and 264.82kg/acre *higher* than in monocrop plots during both good and bad seasons, mixed crop plots fail to bring about improved household income, as economic rent is significantly lower in mixed crop plots - an inconsistency best explained by the difference in factors of production for mixed and monocrop plots. Monocrop plots experience lower cost and labour intensities than farmers of mixed crop plots, exhibiting characteristics of economies of scale (ES) - this finding corroborates Waddington et al. (2007) and Rusinamhodzi et al. (2012) who describe the practice of intercropping as more labour intensive than monocropping. To examine more closely the role of cost and labour intensities, individual cost and labour inputs for monocrop versus mixed crop plots is compared, controlling once again for acreage. Table 10 outlines these cost and labour inputs differences, using monocrop plots. Bold entries denote significant characteristics common across both LM4 and LM5 zones.

	*** = α<0.01 ** = α<0.05 * = α<0.1	**Cost and Labour Inputs, Mixed vs. Monocrop Plots, Where: Mixed Crop Plot = 0, Monocrop Plot = 1**	
		LM4	**LM5**
Labour Inputs (man-day/acre)	*Bush Clearing*	-0.17	-3.14
	Burning	0.26 ***	0.03
	Cleaning Leftovers	-0.81	-2.84 ***
	Soil Conservation	**-2.88 ****	**-2.83 ****
	Manuring	**-4.93 *****	**-6.12 *****
	Ploughing	**-3.36 *****	**-1.55 *****
	Fertilising	**-0.88 *****	**-0.60 *****
	Planting	0.035	-2.81 ***
	First Weeding	**-3.97 *****	**-9.12 *****
	Second Weeding	**-4.94 *****	**-5.38 *****
	Third Weeding	**-1.01 ****	**-2.23 *****
	First Spraying	-0.27	-1.09 **
	Second Spraying	-0.20	-0.34
	Bird Scaring	6.65	14.92 ***
	Harvesting	**-10.99 *****	**-13.16 *****
	Drying	**-6.44 *****	**-5.99 *****
	Threshing	**-6.54 *****	**-8.73 *****
	Storage	**-3.24 ****	**-2.61 ***
Cost Inputs (KSH/acre)	*Improved Seeds*	**-544.64 *****	**-688.43 *****
	Local Seeds	-338.83 ***	-28.16
	Natural Field Pesticides	47.67*	-
	Synthetic Field Pesticides	-103.77	-155.00 *
	Natural Storage Pesticides	-7.97	14.20
	Synthetic Storage Pesticides	-209.93	3.30
	Manure (Organic Fertiliser)	-2149.91 **	-835.29
	Compost (Organic Fertiliser)	-367.07 **	-
	Treated Irrigation	-	-

	Not Treated Irrigation	-	-
	Phosphate (Inorganic Fertiliser)	-152.09 **	-20.36
	Nitrogen (Inorganic Fertiliser)	-221.27 **	-10.06
	Household Labour	**-8265.08 *** **	**-7250.74 *** **
	Non-Household Labour	-2362.66 ***	776.05
	Pre-Harvest Technology	**-1038.08 ** **	**-1239.17 *** **
	Post-Harvest Technology	-44.44	-29.56
	Distance to Market With Transport	357.60 ***	20.37
	Distance to Market Without Transport	-34.33	-30.82
	Cess	135.06	37.27

Table 10 – Mixed crop plot versus monocrop plot cost and labour inputs.
Where Mixed Crop Plot=0 & Monocrop Plot=1.
Bold entries denote significant characteristics common across both LM4 and LM5 zones.

Examining the cost and labour inputs for monocrop plots, there is evidence of economies of scale and skill and technology specialisation. Monocrop plot farmers spend less time on pre-harvest and post-harvest manual labour activities including manuring, fertilising, ploughing, harvesting, threshing, drying and storing their crop. This is a likely explanation of why monocrop farmers experience a lower labour cost. Household labour cost is dramatically lower for farmers of monocrop plots in the LM4 and LM5 zones, as is non-household labour in the LM4 zone. While non-household labour is (not significantly) higher for monocrop plots in LM5, this effect is not great enough to counter the higher household labour cost, demonstrating the overall lower labour requirements for monocrop plots.

4.4.2 Breaking Even

Table 11 overviews the frequency of economic rent break even by Agro-Ecological Zone and cropping system type.

	Percentage of Plots that Break Even (Economic Rent)	
	Mixed Crop Plots	***Monocrop Plots***
LM4 Good Season	46.6%	74.3%
LM5 Good Season	46.7%	41.7%
LM4 Bad Season	19.9%	30.5%
LM5 Bad Season	11.2%	15.7%

Table 11 - Percentage of plots that achieve economic rent 'break even' by AEZ and cropping system type.

In three out of four scenarios, monocrop plots more frequently achieved economic rent break even than mixed crop plots. It must be highlighted that acreage is not controlled for in Table 11's descriptive analysis. Table 12 details the logistic regression output.

*** = α<0.01 ** = α<0.05 * = α<0.1	**Logit Model Coefficients - Economic Rent Break Even** **Where LM4=0 LM5=1, Mixed Crop Plot=0 Monocrop Plot=1**		
	Good Season	***Bad Season***	***n***
Model 1			
AEZ	-0.55 (0.20) ***	-0.72 (0.26) ***	473
Cropping System	0.704(0.20) ***	0.64 (0.25) ***	473
Acreage	0.80 (0.20) ***	0.41 (0.09) ***	473
Model 2			
AEZ	-0.58 (0.20) ***	-0.77 (0.27) ***	473
Cowpeas	0.09 (0.36)	0.35 (0.45)	473
Green Grams	1.72 (0.38) ***	1.06 (0.35) ***	473
Maize	-0.02 (0.40)	-0.50 (0.64)	473
Millet	0.72 (0.33) **	1.31 (0.39) ***	473
Pigeon Peas	0.56 (0.73)	0.61 (0.89)	473
Sorghum	1.11 (0.35) ***	0.14 (0.49)	473
Acreage	0.81 (0.20) ***	0.41 (0.10) ***	473

Table 12 – Logit regression model coefficients, where LM4=0 LM5=1, Mixed Crop Plot=0 Monocrop Plot=1.

15 out of 22 'economic rent break even' coefficients in the logistic regression displayed significance. In a logistic regression model, coefficients describe the change in log

odds outcome for a one-unit increase in the predictor variable (UCLA, n.d.). Critically, model I shows that farmers in the LM5 AEZ are 55 per cent and 72 per cent less likely to break even in good and bad seasons, respectively, than farmers in the LM4 zone, controlling for plot size and cropping system. This result strongly supports the first hypothesis of the paper. In the second model, more evidence rejects the second hypothesis - in both good and bad seasons monocrop plots positively increase farmers' likelihood of breaking even. Turning to logistic model II, it is demonstrated that in a good season, individual plots of green grams, millet and sorghum, all High Value Traditional Crops, largely increase the log odds of breaking even in a good season. In a bad season, green grams and millet both contribute highly to the likelihood of breaking even.

Table 13 presents the predicted probability of economic rent 'break even' in both good and bad seasons for LM4/LM5 monocrop plots, mixed crop plots and individual monocrops, controlling for plot size (acreage). Figure 5 looks at the probability of breaking even in both good and bad seasons, not breaking even in neither season, and breaking even in either good or bad season, for specific crops in each zone - also controlling for plot size.

	Probability of Economic Rent 'Break Even'	
	Good Season	**Bad Season**
LM4 Mixed Crop	0.52	0.18
LM5 Mixed Crop	0.38	0.10
LM4 Monocrop	0.68	0.30
LM5 Monocrop	0.55	0.17
LM4 Cowpeas	0.54	0.25
LM5 Cowpeas	0.40	0.13
LM4 Green Grams	0.86	0.40
LM5 Green Grams	0.77	0.23
LM4 Maize	0.51	0.12
LM5 Maize	0.37	0.06
LM4 Millet	0.69	0.46
LM5 Millet	0.55	0.28
LM4 Pigeon Peas	0.65	0.30
LM4 Sorghum	0.76	0.21
LM5 Sorghum	0.64	0.11

Table 13 – Predicted probability of economic rent 'break even' in good and bad seasons.

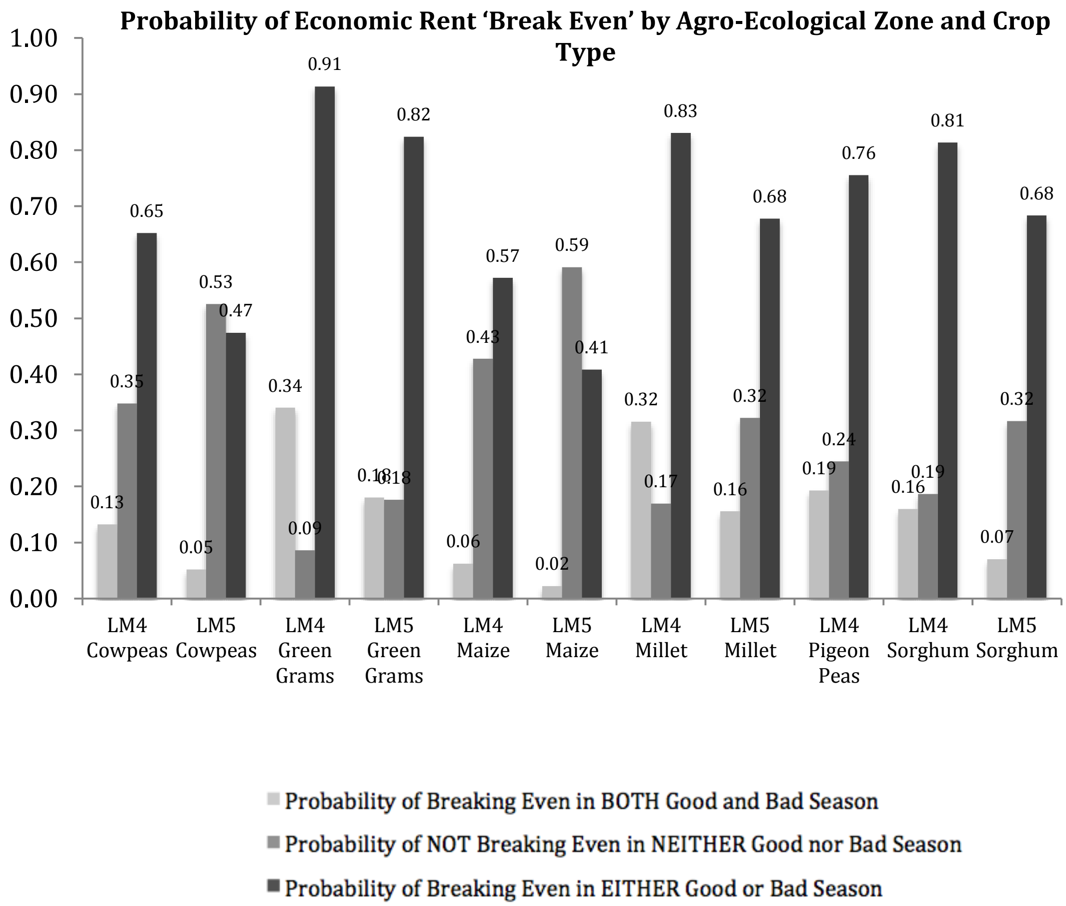


Figure 5 – Probability of economic rent 'break even' by AEZ and crop type.

Given two plots of the same size, monocrop plots in the study area more likely to break even in good and bad seasons, across both Agro-Ecological Zones. In a good season, monocrop plots in the LM4 and LM5 zones are 31 per cent and 45 per cent more likely to break even than mixed crop plots, respectively. In a bad season, the trend is even more pronounced: LM4 monocrop plots are 67 per cent more likely to break even, while LM5 monocrop plots increase the likelihood by 70 per cent.

Looking at specific crops, HVTCs exceled in the study area in both seasons. In a good season, green grams, millet and sorghum offer farmers in both zones a high probability of breaking even. LM4 and LM5 farmers of green grams, for example, have a 91 per cent and 82 per cent chance, respectively, of breaking even in either good or bad season. In a bad season, green grams and millet continue to outperform in both zones, offering the highest probability of breaking even compared to other crops. In a bad season, however, sorghum does not perform well with the probability of breaking even remaining very low while showing no statistical difference between good and bad seasons. Overall, maize, the non-HVTC crop in the sample, performed very poorly, especially in bad seasons, confirming the findings of Waddington et al (2007). In the LM4 zone, farmers of maize plots have only a 6 per cent chance of breaking even in both seasons while LM5 farmers have only a 2 per cent chance.

4.5 Discussion

Experiencing a higher yield in a good season and greater revenue productivity of labour both good and bad seasons, wetter-zone LM4 farmers are overall more likely break even than their counterpart farmers in the drier LM5 zone. These Agro-Ecological Zone results support the preliminary hypothesis, confirming the direct relationship between exogenous environmental and climatic variables and agricultural production at the household level in Machakos, Makueni and Tharaka-Nithi Counties. While not directly employing a Ricardian model, the findings corroborate those of Mendelsohn, Nordhaus and Shaw (1994) within the confines of smallholder farming across two Agro-Ecological Zones of semi-arid Kenya. Beyond 'adding to the pile' of regional food security knowledge, how can the AEZ results inform future policymakers when outlining a vision of smallholder agriculture in semi-arid regions of Kenya?

In a way, this break-even analysis is misleadingly optimistic, overshadowing the tragically frail nature of food security in Kenya through terms such as 'increasingly the probability of breaking even' and 'most likely to break even'. Only 52 per cent of plots in the sample broke even during a good season - the equivalent to a farmer tossing a coin, believing that this year will work. In a bad season, the probability is even more disheartening as a mere 19 per cent of plots make it. Inevitably, these figures say more about the frailty of smallholder in arid and semi-arid lands than the entire regression analysis itself, delineating the harsh backdrop against which Kenyan agriculture takes place. Although farmers in the wetter zone are more likely to break even, chances remain slim and are only getting slimmer as climate change rears its ugly head - under a climate change business-as-usual (BAU) scenario, the coin toss slowly becomes more unbalanced and less predictable. Developing country smallholder farmers are most vulnerable to the impacts of climate change (FAO, 2013a), characterised by increased frequency and intensity of drought in the region (Alila and Atieno, 2006). Arid and semi-arid lands are especially vulnerable to these effects (FAO, 2013b). By, 2030 rainfall variability is expected to increase by 20 per cent in Kenya (Kabubo-Mariara and Karanja, 2007) and within Lower Midland zones there has been a 0.35°C increase in mean temperature in recent history (Ralph et al., 2006).

Noting the impacts of "unreliable weather patterns and effects of climate change", the Kenyan government describes climate change as an 'emerging issue and challenge' to the agricultural sector (Government of the Republic of Kenya, 2013, p. 52) and has developed a national climate change strategy (Maina et al., 2013). In the face of growing climate uncertainty, Kenyan policymakers must promote a novel vision of agriculture in ASALs, based on traditional crop adoption and an understanding of farmers' needs. This vision can be realised by devising agriculture policy through the "lens of climate change" (FAO, 2013a), integrating the FAO's climate-smart agriculture framework. CSA - "… an approach to developing the technical policy and investment conditions to achieve sustainable agricultural development for food security under climate change" (FAO, 2013a, p. ix) – comprises three pillars: (i) sustainably increasing agricultural productivity and incomes; (ii) adapting and building resilience to climate change and; (iii) reducing and or removing greenhouse gas emissions, where possible (FAO, 2013a). This holistic approach seeks to improve the livelihoods of smallholders and, fundamentally, aims to increase the resilience of local farming systems. Resilience, the "capacity of systems, communities households or individuals to prevent, mitigate or cope with risk and recover from shocks", is increased through the CSA framework by "reducing vulnerabilities and increasing adaptive capacity" (FAO, 2013a, pp. 19–20). With this framework in hand and an understanding of the increasingly challenging nature of smallholder agriculture in ASALs, how can these results contribute to a climate-smart Kenya?

Turning first to the analysis of cropping system, mixed or monocrop plot, there exists interesting and unanticipated results in desperate need of analysis – two key points emerge. First, less-surprisingly, the importance of mixed cropping as an agricultural practice in semi-arid regions of Kenya is confirmed, finding approximately half of all plots surveyed to be mixed crop plots. This outcome supports that of Songa et al. (2010), who find more than 50 per cent of maize farmers in semi-arid Kenya grew maize in association with other crops (Songa et al., 2002), and Fordham (1983), who describes mixed cropping as the most widely used cropping system by smallholder farmers in tropical Africa (Fordham, 1983). The second hypothesis, however, based on anecdotal evidence from farmers that mixed crop plots are favourable in semi-arid Kenya, did not hold. Mixed crop plots exhibited both higher cost and labour intensities than monocrop plots. Similarly, mixed crop plots yield a significantly lower economic rent in both good and bad seasons and, given two plots of the same size, monocrop plots are more likely to break even in both good and bad seasons. Why, therefore, do farmers perceive mixed crop plots to be superior if they break even less frequently with their cultivation? Before eyebrow-raising (seemingly CSA-contradicting) conclusions are drawn, a more in-depth analysis is needed of economies of scale, examining the relationship between economic rent, yield and the role of factors of production.

Comparing production and economic rent between monocrop and mixed crop plots helps explain the discrepancy between farmers' strong, positive perception of mixed cropping and the monocrop-favouring results of the regression analysis. Economically speaking, monocrop plots are more efficient, specialised production units, thanks to improved technologies and "economies of scale in the production and distribution of inputs, machines, and especially processing and trade" (FAO, 2013a, p. 23). In the previous section, it was noted that labour allocation to manuring and fertilising is significantly lower among monocrop plots. While these farmers may spend significantly less time on their application, this does not necessarily imply a lower *quantity* of fertiliser is actually applied. Looking at the cost inputs, however, monocrop farmers in both zones spend less on both organic and inorganic fertilisers, with the trend especially apparent in the LM4 zone. A combination of two scenarios is likely here: either monocrop plot farmers receive a lower, bulk price for fertiliser and spend less time on their application because it is more methodologically applied – that is, the exact required quantity of fertiliser is known from previous years (skill specialisation) or; monocrop plot farmers buy a lower quantity of fertiliser and, therefore, spend less time applying it because there is inherently not as much to go around. Without further research on fertiliser quantity applied by cropping system, the nature of this relationship cannot be concretely determined. Similarly unsure, monocrop plot farmers in both zones spend less time on soil conservation – a common practice among smallholders in the region involving the placement of stones and living or non-living material on top of soil to reduce the effects of soil erosion by run-offs (Hudson, 1987). Again, two logically diametric scenarios may explain this: monocrop plot farmers 'care' less about soil conservation and long-term soil quality, or; less time is required on conservation because soil degradation between harvest seasons is lower under these conditions. Once again, further case-specific data collection in semi-arid Kenya is required before this can be fully understood.

Understanding that mixed crop plots are more labour intensive, let us now look at who actually works on the farm. Some striking trends emerge when examining household labour versus non-household hired labour across both cropping systems. Compared to monocrop plots, farmers of mixed crop plots are significantly more dependent on household labour. This labour, however, is not 'free'. By choosing to work on their own plot for the day, farmers forego a day's wage he or she could have obtained by working elsewhere – this is the opportunity cost of household labour. One large assumption is commonly made vis-à-vis the opportunity cost of labour: the existence of alternative income-generating activities. In this case, however, evidence is provided to the existence of local labour demand as farmers in the study area supplement household labour with non-household, paid (minimum wage) labour on the farm. Given this existing but limited labour market context, farmers will assumedly supply household labour to the plot until the opportunity cost of labour is greater than the net benefit of production. In a good season for mixed crop plots, the ratio of household labour cost to total revenue for a plot amounts to 0.66 - in a bad season, however, the ratio is a poor 1.65. In the study area, agriculture cannot be only measured in production or labour cost terms, but it requires an understanding of the importance of social capital to decision making as agriculture is the traditional occupation for communities.

Closely examining the cost and labour input differences associated with each cropping system, a clear portrait is painted: yielding more crop per acre of land, farmers of mixed crop plots may be mislead into believing this strong production translates into improved household income. However, the high factors of production associated with mixed crop plots - notably labour cost - cancel out any yield benefits in favour of monocrop plots.

Critics at this point will argue that this support for smallholder monocrop plots is in opposition to the principles of climate-smart agriculture. This paper does not, however, advocate widespread, intensive monoculture, for the environmental implications are well documented, including deteriorating water quality, soil erosion, sedimentation and long term total factor productivity decline (Byerlee and Ali, 1999; Pingali et al., 1997; Thapa and Gaiha, 2011; Trimble and Goudie, 2008). What is proposed here is small monocrop plot diversification, involving multiple, unique monocrop plots. Monocrop plots are that in themselves, merely a 'plot' (remembering that in this sample the average plot size was just over 1 acre, with each farmer holding approximately 3 diverse plots) and not an entire farm of one crop. Furthermore, ensuring plots are seasonally rotated among different crops will reduce the 'severe consequences of agro-simplification' (Snapp et al., 2010). Crop rotation, notably the introduction of legumes in a rotation cycle, allows for higher agricultural productivity compared to monoculture, protecting the soil against degradation and reducing the need for fertiliser intensification over time (Peter and Runge-Metzger, 1994; Snapp, 1998; Snapp et al., 2002, 2010; Thierfelder et al., 2012).

What will emerge under this approach, therefore, is a community of farms containing multiple rotating monocrop plots – what I describe as 'mosaic smallholder monocropping'. This approach - very different to the Midwest-esque vision of monoculture agriculture so-often brought to mind when term 'monocrop' is spoken - is a logical extension of Jodha (1980), who notes: "most of the farmer's objectives can be achieved by diversification of cropping… splitting the available land into several plots/sub-plots and planting them with different sole crops…" (Jodha, 1980, p. 437). With strict crop rotation, small plots and increased household income, the primary objective of CSA is met: sustainably increasing agricultural productivity and incomes (FAO, 2013a).

The results of the individual crop performance test also inform climate-smart agricultural policy in a more direct manner. Drought-resilient, High Value Traditional Crops excelled, notably millet, green grams and sorghum in a good season, and millet and green grams in a bad season. Offering a 91 per cent and 82 per cent chance of breaking even in *either* good or bad season in LM4 and LM5 zones, respectively, green grams can improve household food security when compared to the cultivation of other crops, especially maize, the non-HVTC crop in the sample. These results provide supporting evidence for the Kenyan Ministry of Agriculture's recent and ongoing HVTC campaign that promotes drought-resistant crops in ASALs (Government of the Republic of Kenya, 2010; Maina et al., 2013). Government supported HVTC adoption achieves the secondary objective of CSA: "adapting and building resilience to climate change" (FAO, 2013a). Strong performers in a bad season, HVTCs decrease overall household agricultural failure risk, increasing the resilience of farming systems to exogenous shocks, notably the increased frequency and intensity of drought brought about by climate change in the region (Alila and Atieno, 2006).

Combining the analysis of mosaic monocropping and HVTCs, system-wide resilience can be increased through appropriate institutional approaches to climate-smart agriculture. Recent advancements in institutional research aim at integrating governance regimes within and across scales (Young, 2002; Brondizio et al., 2009). Following these analyses, nested institutional theory focuses on coordination among institutions (Yashiro et al., 2013), addressing the "regime complexes" of large environmental institutions, so-often characterised by inherent conflicting interests (Zelli, 2011; Zelli and van Asselt, 2013). This approach allows institutions to "coordinate horizontally across geographic space" while "enabling institutions to also interact vertically… across political boundaries and secure an even distribution of those services…" (Yashiro et al., 2013, p. 195). Logically intuitive, a nested institutional framework brings consistency and coordination among institutions, within and between scales (Yashiro et al., 2013). This holistic approach is fundamental for food security policies in the region - in such a frail agro-economic context, decreasing household risk can only be one building block of a resilient system. Statistically speaking, even if growing the 'perfect combination' of crops, farmers will eventually fail. A climate-smart framework must embed resilience at all rungs of the ladder in the agricultural sector, ensuring safeguards exist for when the 'coin toss' provides less favourable results. A nested institutional approach to food security in semi-arid Kenya will involve three scales (household, community and national) of equal importance, eschewing many elements previously discussed.

At the household scale, resilience is improved through the mechanisms previously outlined - increased adoption of HVTCs and mosaic monocropping reduce the vulnerability of households to exogenous shocks and improve income through economies of scale and skill specialisation.

Moving to the community level, three simultaneous strategies can protect farmers above and beyond measures taken within the farm. First, through collective action undertaken by local farmer groups, smallholders can agree to allocate one plot per household to 'community crops' where all yield is shared among member households in the group. With a large share of households in a community subscribed to the system, each farmer will have a variety of crops for consumption. This approach addresses the limitations placed on household dietary diversity by the mosaic monocrop model: with on average 3 plots per household, the ownership of solely monocrop plots either restricts the diets of farmers or confines farmers to commercial crops. Incorporating farmer groups and community agriculture into this model, farmers can benefit from a wide range of skill and technology specialisation available from farmers throughout the community (including existing economies of scale), while simultaneously supporting the 'dietary needs' goal of mixed crop plots, as outlined by Songa et al. (2010). Second, community-level strategies to integrated pest management (IPM) can collectively improve the wellbeing of all farmers. Pest management is an inherently 'social problem' as one farmer's profits are a function of his or her neighbour's pest control practises (Norgaard, 1976). Collectively addressing common pest infestations in the village, farmers can improve their income compared to individualistic behaviour (Norgaard, 1976). Overcoming the organisational challenges associated with collective action, this community IPM model is driven by local institutions including farmer field schools (FFS) and membership based farmer groups (FAO, 2002). Third, with only 150,000-200,000 subscribers across all economic sectors, the Kenyan microinsurance sector has strong growth potential. In their Vision 2030 Outlook, the Kenyan Government identifies "enhanced access to insurance at affordable rates" in lower ends of the market as a key initiative (Government of the Republic of Kenya, 2014). Of particular interest are Insurances Based on Meteorological Indices (IBMI) schemes - also known as index-based insurance – which offer smallholders protection from poor seasonal climatic conditions. Unlike traditional insurance which covers against crop loss, index-based insurance triggers indemnification when some meteorological threshold is not reached, such as annual rainfall (a correlation of yield in itself) (Leblois and Quirion, 2013).

Given that IBMI uses meteorological conditions as the threshold, crop losses cannot be falsified and the moral hazard of traditional insurance is removed. Furthermore, this feature largely reduces management costs as individual claimant's fields do not need to be inspected (Osgood et al., 2007; Suarez and Linnerooth-Bayer, 2010; Peterson, 2012). Pilot projects in India, Malawi and Ethiopia have provided strong evidence for the ability of microinsurance to decrease smallholder vulnerability to climate change (Peterson, 2012; Leblois and Quirion, 2013) and further evidence from Malawi suggests a positive cyclical relationship between microinsurance and the microcredit industry – farmers previously-excluded from the credit market may now have access to micro-loans because of the confidence provided by microinsurance guarantees (Osgood et al., 2007).

Finally, at the national level this nested institutional climate-smart approach requires key 'enabling institutions' for policy-framework development and maintenance, ensuring farmers having access the "necessary quality and quantity of key resources" (FAO, 2011, p. 86). Applying Pretty and others' (2011) requirements for sustainable intensification to the case of smallholder agriculture in Kenya, four key challenges and opportunities are identified: (i) the Kenyan government must continue its support for sustainable smallholder agriculture, materialising this agenda through robust policies and public good provision, including but not limited to: seed subsidies for drought-resilient HVTCs, transport infrastructure investment, market supply chain development, future price signals, continued research for improved HVTC varieties through research agencies such as the Kenya Agricultural Research Institute (KARI) and storage facilities. (ii) In addition to providing a robust regulatory framework for the microinsurance industry, Government must ensure farmers and farmer groups have adequate access to finance through microfinance institutions and rural banking (Pretty et al., 2011). Access to finance is a limiting factor for agricultural productivity and food security in Kenya (Government of the Republic of Kenya, 2010). Smallholder farmers often require small loans but are denied by traditional lending institutions and conventional banks (Pretty et al., 2011) because of the 'inherent risks' associated with agricultural finance (IFAD & CGAP, 2006). (iii) Widespread community-level education campaigns, including farm field schools, videos, social media and farmer-trainer programmes (Pretty et al., 2011) must improve farmers' knowledge of HVTCs and climate change. Education will provide farmers with the skills and knowledge necessary to fully understand and negotiate microfinance contracts, gauge agricultural risk and understand the key issues surrounding long-term soil fertility rates. (iv) While HVTC-adoption aligns with a key principle of sustainable crop production intensification (SCPI) through the use of "well adapted, high yielding varieties and good quality seeds" (FAO, 2011, p. 11), this will require effective seed sector regulation and support to "…ensure farmers' access to quality seeds of varieties that meet their production, consumption and marketing conditions. Access implies affordability, available range of appropriate varietal material, and having information about the adaptation of the variety" (FAO, 2011, p. 83). There exists a clear opportunity for Government-industry public-private partnerships (PPP); seed sector support and regulation, however, must also take into account the informal sector, as almost 80 per cent of all seeds in Kenya are obtained through the informal sector (Mbata, 2013). Neglecting the role of the informal sector provides challenges for increased adoption of HVTCs, as farmers may be ill informed as to Government-supported seeds, their drought-resilient capabilities and their potential for income and food security gains. Informal sector support must be coupled with elements of social capital formation and knowledge building previously mentioned to bridge this informal sector knowledge-gap, ensuring farmers are equipped with the knowledge and skills necessary for climate-smart agriculture.

5 Deploying the Magnifying Glass: The Complexity of Interventions

Adhering to the first and second stages of van Mil et al.'s (2014) systematic approach to addressing complex problems in agriculture and food systems, this first manuscript delineated the frail state of smallholder agriculture in eighteen villages of semi-arid Kenya based on observation and statistics, harvesting information on the different levels within this complex system and ultimately offered data-based policy inferences (intervention strategies) rooted in the FAO's climate-smart agriculture framework. Equipped with a broad understanding of the frail condition of smallholder agriculture in Kenya's Machakos, Makueni and Tharaka-Nithi Counties, notably the struggle farmers face each season vis-à-vis breaking even, let us look more closely at the effectiveness of interventions (van Mil et al., 2014) by examining the barriers associated with adopting climate-smart agriculture practices.

Agriculture and food systems are inherently ‘complex systems’ – both temporally and disciplinary - characterised by interdependence, continuous dynamics, adaptation and self-organisation, involving innumerable interdependent networks embedded within material, life, behavioural and socio-economic sciences (van Mil et al., 2014). Nourish (2014), an educational initiative aimed at raising awareness of food systems and sustainability, graphically captures this complex system (Figure 6) and powerfully portrays the interdependence of networks across disciplines, notably society, the economy, farm inputs and the environment.

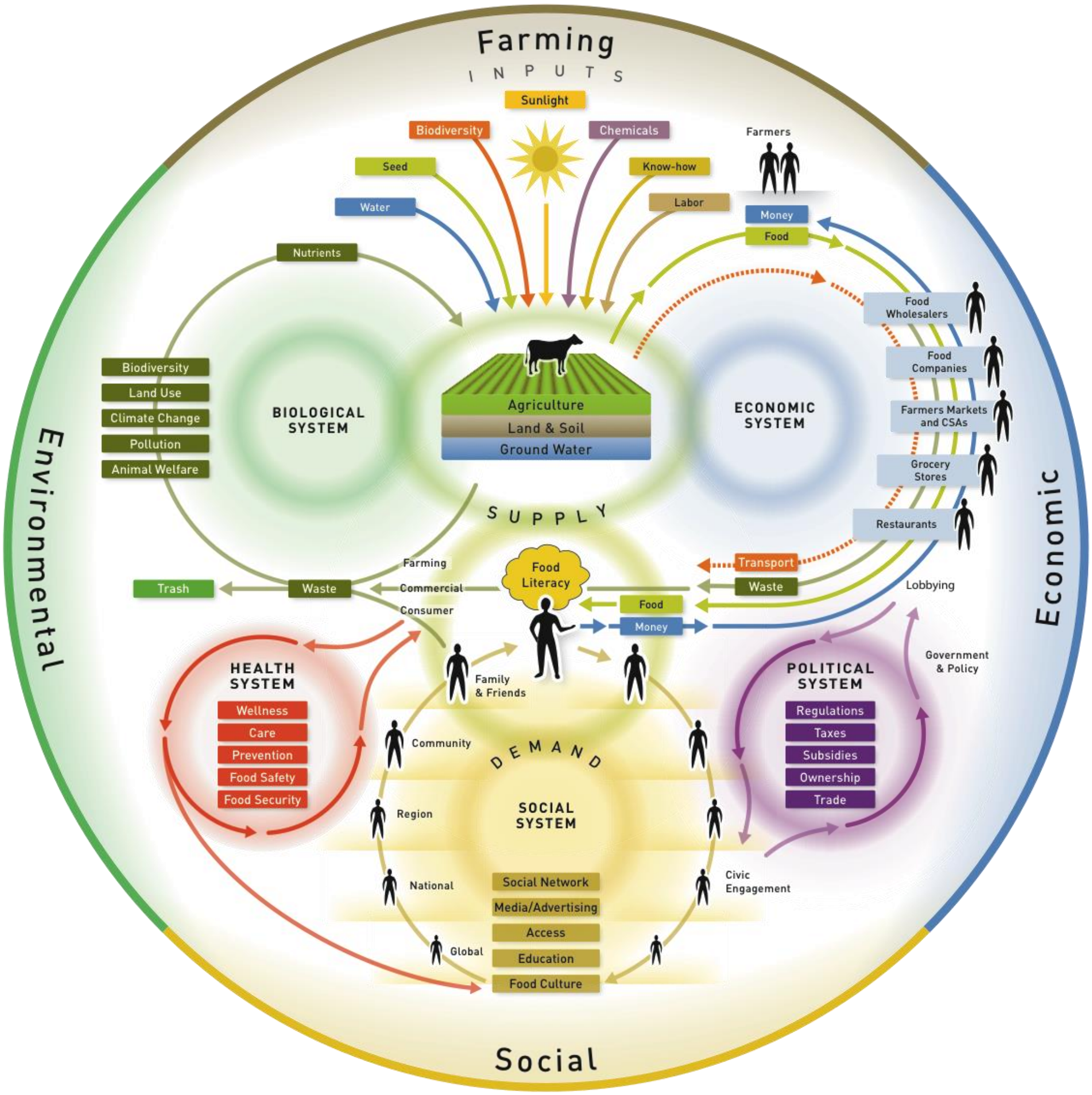


Figure 6 – Agriculture and food system map (Nourish, 2014).

Given this multifaceted, interwoven system, increasing the resilience of agriculture to climate change is an inherently complex challenge (Gregory et al., 2005; Howden et al., 2007; FAO, IFAD and WFP, 2014) - each CSA policy recommendation requires a deep understanding of the economic, cultural, ecological and institutional barriers to their greater adoption and merits a multi-year development programme or PhD thesis. Reducing dependence on water-intensive maize in the light of climate change, for example, requires not only widespread changes to industry supply chains and seed research and development, but also extensive education programmes for behaviour and consumption change at the household level. Similarly, a switch to 'mosaic-monocropping' commands a deep understanding of soil conservation practices and necessitates greater market access (and therefore education) for smallholders to ensure dietary diversity.

This difficulty of implementing appropriate interventions in complex agriculture and food systems is captured by van Mil et al. (2014, p. 22), who state: "Firstly … a response in one system usually cannot be inferred from responses of individual factors that are present at more detailed levels in that system. Secondly, an intervention in one system may cause changes in other systems, which reversely may induce changes in the original system….". In short, when addressing complexity, "…. we need to be aware that there will always be a lack of knowledge, meaning that our predictions will not always come true" (Allen, 2012). Given a range of climate change agriculture mitigation interventions, each strikingly large and complex with a variety of interlocking factors (Jones and Thornton, 2003; Morton, 2007; Schmidhuber and Tubiello, 2007; Verchot et al., 2007; Laukkonen et al., 2009; Maina et al., 2013; FAO, IFAD and WFP, 2014), the question arises: where do we possibly begin?

Not because I necessarily rank it as the most pressing or critical challenge facing smallholder farmers in the region, but based on striking and intriguing anecdotal evidence (later supported by data) provided by farmers in the study area, I choose to examine a barrier to the greater adoption of High Value Traditional Crops – an important (and policy-relevant) climate-smart agriculture practice. Accordingly, the next manuscript of this thesis presents a case study, examining pest management practices of HVTC farmers, in particular millet and sorghum, as a barrier to their greater adoption. Beyond addressing the HVTC-policy recommendation outlined in the previous section, this case study touches on four out of six of the government's 'challenges and opportunities', as outlined in Table 1: (i) *challenge*: pre- and post-harvest crop losses; (ii) *opportunity*: potential for increasing production; (iii) *opportunity*: potential for increasing yield; (iv) *opportunity*: improving land use and crop production (Government of the Republic of Kenya, 2010).

Presenting a case study, this thesis now switches gears in three important ways: (i) as previously mentioned, the paper moves away from statistical analysis, policy recommendations and the general examination of the dataset through hypothesis testing. While by no means exhausted, this objective was accomplished in the previous chapter. Instead, a 'magnifying glass' approach is adopted, closely examining one particular challenge for smallholder farmers. In this context, I move onto step three in van Mil et al.'s (2014) systematic approach to addressing complex problems in agriculture and food systems: estimate the effectiveness of interventions (van Mil et al., 2014); (ii) I transition from a theme of frailty to one of complexity. Through wide-ranging data analysis, the previous chapter exposed the frailty of smallholder systems by analysing endogenous and exogenous conditions of the farm and their respective abilities to inhibit or facilitate agricultural productivity. The following manuscript, however, through a 'magnifying glass' approach, examines the complexity of the system and the challenges associated with implementing even the most seemingly-simple development interventions; (iii) although the paper continues to be policy and development relevant, an increasingly theoretical approach is adopted. Examining labour allocation to particular pest management practices in the study area, farmers' behaviour is more broadly connected to externality theory in economics and I ultimately offer, through the 'lens' of ecological economics, a blunt, theoretical critique of environment and resource economic (ERE) prescriptions for *so-called* externalities.

6 The Tragedy of Bird Scaring

A version of this chapter was submitted to *Ecological Economics* on 26th September 2014.

Matthew Ainsley[a] & Dr. Nicolas Kosoy[a,*]

[a] McGill University Department of Natural Resource Sciences
21111 Lakeshore Road,
Ste. Anne de Bellevue, Quebec, Canada
+1 514-398-7773

*Corresponding author: nicolas.kosoy@mcgill.ca

6.1 Introduction

In some regions of Africa, 90% of farmers report crop loss to wildlife (Hill, 1997). In particular, bird crop raids are usual events in many agricultural areas of Africa, requiring farmers to sit and invigilate their lands for long hours - an endless, isolating and debilitating process that presents an important challenge for socio-economic development and food security at the household level. In general, efforts have been devoted to minimize human-wildlife conflict by examining compensatory schemes to crop losses (Rollins and Briggs III, 1996; Wagner et al., 1997; Tassell et al., 1999; Osborn and Park, 2002; Bulte and Rondeau, 2007; Gubbi, 2012), or developing technologies to reduce crop raids (Mallamaire, 1961; Lenné, 2000). In Wisconsin, for instance, residents are compensated for the loss of livestock, pets and hunting dogs (among others) to wolves (Agarwala et al., 2010). A similar scheme in Kenya's Amboseli National Park compensates pastoralists for goats and cows lost to elephants (Bulte and Rondeau, 2005). Very few studies, however, examine labour allocation to pest management at the community level and, even though pest control is inherently a 'social problem' (Norgaard, 1976), the role of collective action and coordination remains poorly understood.

A subsection of the dataset is analysed, examining smallholder agro-economic data from Tharaka-Nithi County only with the goal of understanding farmers' labour allocation to bird scaring in the study area and improving household food security in the region. Comparing plot-level inputs and outputs for a variety of crops, bird scaring is identified as an outlier labour input for sampled farmers of millet and sorghum - drought-resilient, High Value Traditional Crops (HVTCs). Beyond identifying the problem itself, farmers' self-interested behaviour vis-à-vis this challenge provides great insight into economic theory and the way natural ecological phenomena are addressed. With little or no community-level coordination, farmers act in isolation to evict birds from their plot, continuously shifting the negative cost of pests to their neighbour. This behaviour is examined as an externality, testing and theoretically applying environmental and resource economic (ERE) prescriptions for the internalisation of negative externalities in search of a socio-economically efficient and effective outcome. At the core of environment and resource economics' internalisation efforts is the notion that actors engaging in a transaction behave as rational economic agents who only aim at maximizing utility at the individual level, spurring in turn social wellbeing improvements (Varoufakis, 1998). Exhausting ERE's prescriptions, this paper sides with an alternative body of literature which describes externalities as 'cost-shifting practices' (Kapp, 1969; Martinez-Alier, 2002), whereby farmers are characterised as bearers of 'plural rationalities', sometimes making decisions individually and at other times collectively (Temper and Martinez-Alier, 2013). Within this alternative framework, a collective-action based approach to externalities is presented whereby costs are deliberately distributed among all actors, allowing for community-wide social wellbeing improvement.

This paper begins with a brief overview of the existing literature on crop loss to birds in Africa. Subsequently, section 6.3 outlines the particular study site and methodology. In section 6.4, data is presented on effort and time expenditure dedicated to different agricultural activities per cropping system in semi-arid Kenya, highlighting the disproportionate role of bird scaring as a labour input for farmers of certain crops. Section 6.5 critically examines externality theory, theoretically applying and comparing ERE solutions to bird scaring for poor farmers in semi-arid Kenya. Finally, section 6.6 presents a collective action based approach to ecological externalities.

6.2 Pests and Smallholders

Crop losses attributed to wildlife and pests are a costly and uphill battle for farmers in both developing and developed countries. In a broad study, Oerke (2006) estimates the global loss of wheat, cotton and maize to all pests to be 50, 80 and 31 per cent, respectively (Oerke, 2006). Examining crop raids by wild animals in Uganda, Hill (1997) finds 90 per cent of farmers in the study area to experience crop loss as a result of damage by wildlife, with baboons and pigs as the greatest concern (Hill, 1997). In Kenya, examining bean and maize production in highland areas, Grisley (1997) estimates 42 and 57 per cent, respectively, of all crop production is lost to pests (Grisley, 1997). Songa and Songa (1996) find supporting evidence of this loss in Kenya through a study of maize production in semi-arid regions - the study finds infestation and damage by pests to be the third largest constraint on maize production after soil fertility and moisture stress (Songa and Songa, 1996). In particular, lepidopterous cereal stem and cob borers “are considered the most injurious insect pests of maize, sorghum, millet…. in sub-Saharan Africa” (Overholt et al., 2003, p. 131). The importance of stemborers (Kfir, 2002) is underscored in a later study across six Agro-Ecological Zones (UM2, UM3, UM4, LM3, LM4, LM5) by Songa et al. (2002), who find stemborers to be the “… most widely distributed insect pest” (Songa et al., 2002, p. 5), with insecticides as the most commonly used stemborer control method (Songa et al., 2002). In addition to stemborers, Songa et al. (2010) find ground squirrels to be the most widely reported pest – all farmers in LM5, LM4, LM3 and UM4 AEZs reported ground squirrel as a pest of maize – followed by chafer grubs and storage insect pests (Songa et al., 2002). In AEZs relevant to this study, Songa et al. find the following four key pests in decreasing order of importance (Songa et al., 2002):

LM4: squirrels, stemborers, storage insect pests and chafer grubs.
LM5: squirrels, wild pigs, chafer grubs and yellow-necked spur fowls.

Examining solely maize, however, Songa et al.’s study should not be interpreted as an overview of all agricultural pests in Kenya as different pests have various preferences for different crops - in Hill’s Ugandan study, maize, sweet potatoes and cassava were vulnerable to raiding by many animals such as pigs, baboons, porcupines and monkeys, while sorghum was rarely raided by any species other than birds (Hill, 1997).

Throughout many agricultural lands in Africa, bird crop raids are continuous events. In Hill’s (1997) study, for example, birds are described as “major perpetrators of crop-raiding”, with 32 per cent of farmers in the study area reporting crop raids by birds (Hill, 1997). Bird raids are more common if the land is dedicated to the production of rice or drought-resilient, High Value Traditional Crop (HVTC) cereals such as sorghum and millet which are of preference to Western Kenya's migratory red-billed *Quelea* (Mallamaire, 1961; Ruelle and Bruggers, 1982; Manikowski, 1984; Hill, 1997; FAO & WFP, 2009; Esipisu, 2013; One Acre Fund, 2013). Varieties of millet and sorghum seeds are of such preference to birds they are commonly used as wild bird feed in North America and Europe (Anderson and Martin, 1949; FAO, 2005). Given birds preference of HVTCs, crop raids by birds represents a significant barrier to the greater adoption of these 'climate-smart', (FAO, 2013a; Government of the Republic of Kenya, 2013) drought-resilient crops. Despite the importance of HVTCs and Kenyan Government support for their wider adoption (Maina et al., 2013), crop raids and smallholder labour allocation to bird scaring remain poorly understood due to limited research effort and funding (Government of the Republic of Kenya, 2013).

Widely recognised a principle bird pest in Africa, the red-billed *Quelea* is described as "… one of the most notorious pest bird species in the world" (de Mey et al., 2012: p178). Travelling in flocks of hundreds, *Queleas* descend rapidly on farmers' plots during the 'milky' crop maturation phase (Mallamaire, 1961; Elliott, 1979; Ruelle and Bruggers, 1982; Esipisu, 2013), quickly "turning a promising harvest into a barren field" (One Acre Fund, 2013). Exact crop damage inflicted by *Queleas* is difficult to quantify due to insufficient statistical data (Mallamaire, 1961) and the challenges associated with attributing crop loss directly to one species. Surveying the available literature of cereal crop loss to all birds in Africa, de Mey et al. (2012) estimate an average 15-20% loss, with the red-billed *Quelea* the main pest species reported (de Mey et al., 2012). Later, focusing specifically on rice production in the Senegal River Valley, de Mey et al.'s study estimates a 13.2% annual bird damage during the wet seasons of 2003-2007 – this constitutes an average annual economic loss of 4.7 billion CFA francs (USD$9.8m) (de Mey et al., 2012).

Crop raids require farmers to sit and invigilate their lands for long hours (Manikowski, 1988), leading to boredom and a sense of social isolation (Ejiogu and Okoli, 2012). In a seven year study of traditional crop protection methods in Africa, Ruelle and Bruggers (1982) note: "Bird scarers usually are positioned in the middle of a field, often on a platform from where they shout, throw rocks or plant stems, and crack whips or rattle cans as birds enter the field" (Ruelle and Bruggers, 1982: p80). In one Gambian study reported by Ruelle and Bruggers, loss to birds ranged from 17-38% for farmers not conducting any bird scaring (Ruelle and Bruggers, 1982). Studying sorghum fields in Chad, DaCamara-Smeets and Manikowski (1975) find farmers who guard their fields suffer a loss of 4%, compared to a 35% loss for unguarded fields (DaCamara-Smeets and Manikoski, 1975). In addition to human scare actions, some farmers choose to erect nets (Manikowski, 1988), scarecrows or hang obsolete compact discs (Esipisu, 2013) and videotape around the field to deter birds from their plot (One Acre Fund, 2013). Farmers often employ their own household members to scare birds, including children (Katz, 1986, 1991; Bass, 2004; Ejiogu and Okoli, 2012) because they are inexpensive (Ruelle and Bruggers, 1982). This labour allocation highlights the significant (and often neglected) opportunity cost associated with bird scaring and pest management more generally (Chambers et al., 2010). Short-term agriculture and household food security is often prioritised at the expense of non-income generating activities, such as education and play (Hollos, 2002; Ejiogu and Okoli, 2012). Conversely, if farmers allocate their own labour time to bird scaring or choose to hire outside help, fewer resources are available for 'next best' income generating or social activities (Chambers et al., 2010).

6.3 Study Site and Methodology

In this case study, data from Tharaka-Nithi County only is analysed. Located in Kenya's former Eastern Province, Tharaka-Nithi borders Meru County to the North and North East, Kitui County to the East and South East, Embu County to the South and South West. Surveys were conducted in three locations (administrative regions): Chiakariga, Matiri and Nkarini. The general characteristics of each location are outlined in Table 14.

Location (Admin' Region)	AEZ	Soil type	Population Size	Number of Households	Area (Km^2)	Population Density (Person/Km^2)	Mean Rainfall (mm)	Mean Temperature (°C)
Chiakariga	LM5	Rhodic Ferralsol	3960	836	39.9	99	400-1000	22.9-24
Matiri	LM5		2470	488	14.1	175	400-1000	22.9-24
Nkarini	LM4		3496	669	19	184	800-1200	21-23.7

Table 14 – Tharaka-Nithi study site characteristics.

Chiakariga, Matiri and Nkarini were selected because of their close proximity to market (Nairobi), each other and because Lower-Midlands 4 (LM4) and Lower-Midlands 5

(LM5) Agro-Ecological Zones are fully represented. Across Chiakariga, Matiri and Nkarini, six villages were selected: three in the LM4 AEZ and three in the LM5 AEZ. Figure 7 presents a map of Tharaka-Nithi County showing the selected study site locations and villages within Agro-Ecological Zones LM4 and LM5. Consistent with the overall study design, a representative number of households were sampled within each village equivalent to 30 per cent of the entire population, leading to 80 households sampled in total. Once again, this small sample size - a subsection of the overall dataset - and low sampling intensity limit to the external validity of this chapter's findings. In particular, the population of each County is considerably larger than that of each village sampled and a host of agro-ecological and avian conditions exist within the region, rendering the results applicable specifically to the study area. In a similar fashion, we tie these context-specific results to a broader discussion surrounding agricultural interventions and economic theory.

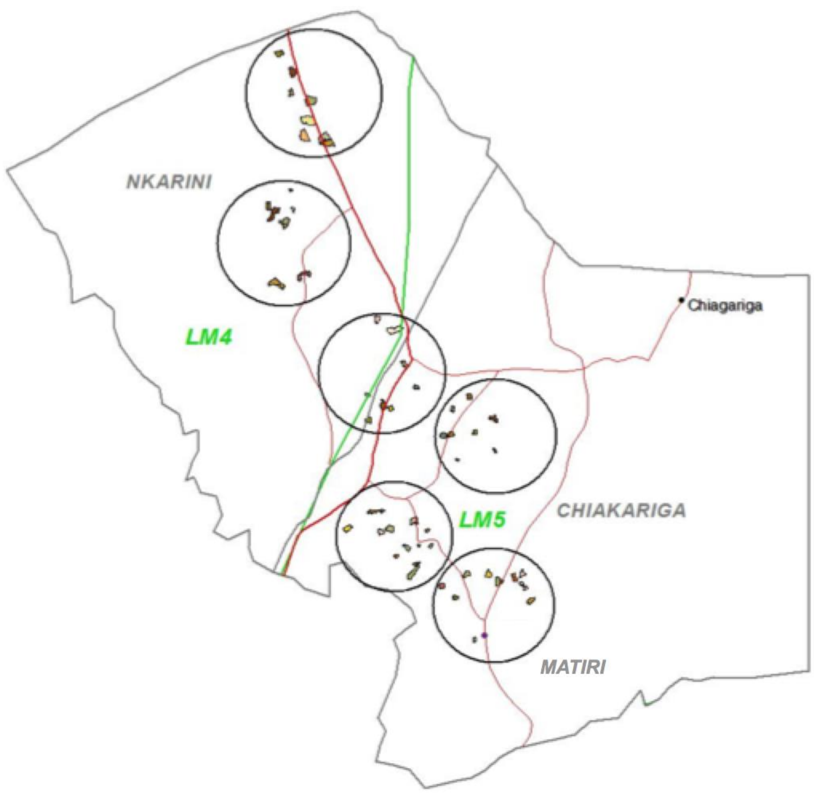


Figure 7 - Selected study site locations and villages within Tharka-Nithi's Agro-Ecological Zones LM4 and LM5.

6.4 Results

At the household level, each farmer cultivated on average 2.9 plots (max: 6, min: 1, SD: 0.3). Five distinctly popular High Value Traditional Crops were grown (in addition to maize): cowpeas, green grams, millet, pigeon peas and sorghum. Table 15 shows the frequency distribution of crops as a function of total plots, including monocrop plots and mixed crop plots.

	LM4 Tharaka-Nithi			LM5 Tharaka-Nithi		
Cropping System	Gantundu	Kamathuri	Kanyange	Kaibugi	Karikithi	Kiiriga
Beans			2%			
Cowpeas	10%	13%	13%	19%	9%	16%
Cowpeas + Maize			2%		3 %	2%
Cowpeas + Millet	5%		7%	6%	9 %	5%
Cowpeas + Pigeon Peas	5%		2%			2%
Cowpeas + Sorghum	5%	3%	7%		6%	2%
Green Grams	15%	23%	20%	19%	24%	19%
Green Grams + Maize	5%		4%	6%	6%	5%
Green Grams + Maize + Pigeon Peas	2%	7%	2 %			2%
Green Grams + Pigeon Peas	5%	3%	2%			5%
Green Grams + Sorghum				3%	3%	5%
Maize	12%	10%	7%	6%	6%	2%
Maize + Pigeon Peas						2%
Millet	17%	13 %	11%	34%	21%	16%
Pigeon Peas	2%		7%			
Pigeon Peas + Sorghum		7%	4 %			
Sorghum	17%	20%	11%	6%	12%	16%

Table 15 - Frequencies of all cropping systems (as a function of total plots) by farmers within the study area.[2]

In the LM4 villages of Gantundu, Kamathuri and Kanyange, the most popular crops (as a percentage of total plots) were millet (17%), green grams (23%) and green grams (20%), respectively. In the LM5 villages of Kaibugi, Karikithi and Kiiriga, the most popular crops were also millet (34%), green grams (24%) and green grams (19%), respectively. Across both AEZs, monocrop plots were more popular than mixed crop plots, representing 74 and 75 per cent of total plots in the LM4 and LM5 zones, respectively.

Labour time devoted to bird scaring depends on the type of crop and the climatic conditions where they are grown. In this study, we organise (Figure 8) labour time spent

[2] Columns may not total 100 per cent because of rounding.

on bird scaring depending on climatic conditions (LM4, LM5), starting with farmers who grow crops other than millet and sorghum (beans, cowpeas, pigeon peas, green grams and maize), moving to farmers who practice mixed cropping with millet and sorghum, finally ending with those who cultivate only and millet and sorghum as monocrops. We expect that those farmers in the latter category will experience the largest time expenditures to bird scaring (Anderson and Martin, 1949; Mallamaire, 1961; Ruelle and Bruggers, 1982; Manikowski, 1984; Hill, 1997; FAO, 2005; FAO & WFP, 2009; Esipisu, 2013; One Acre Fund, 2013).

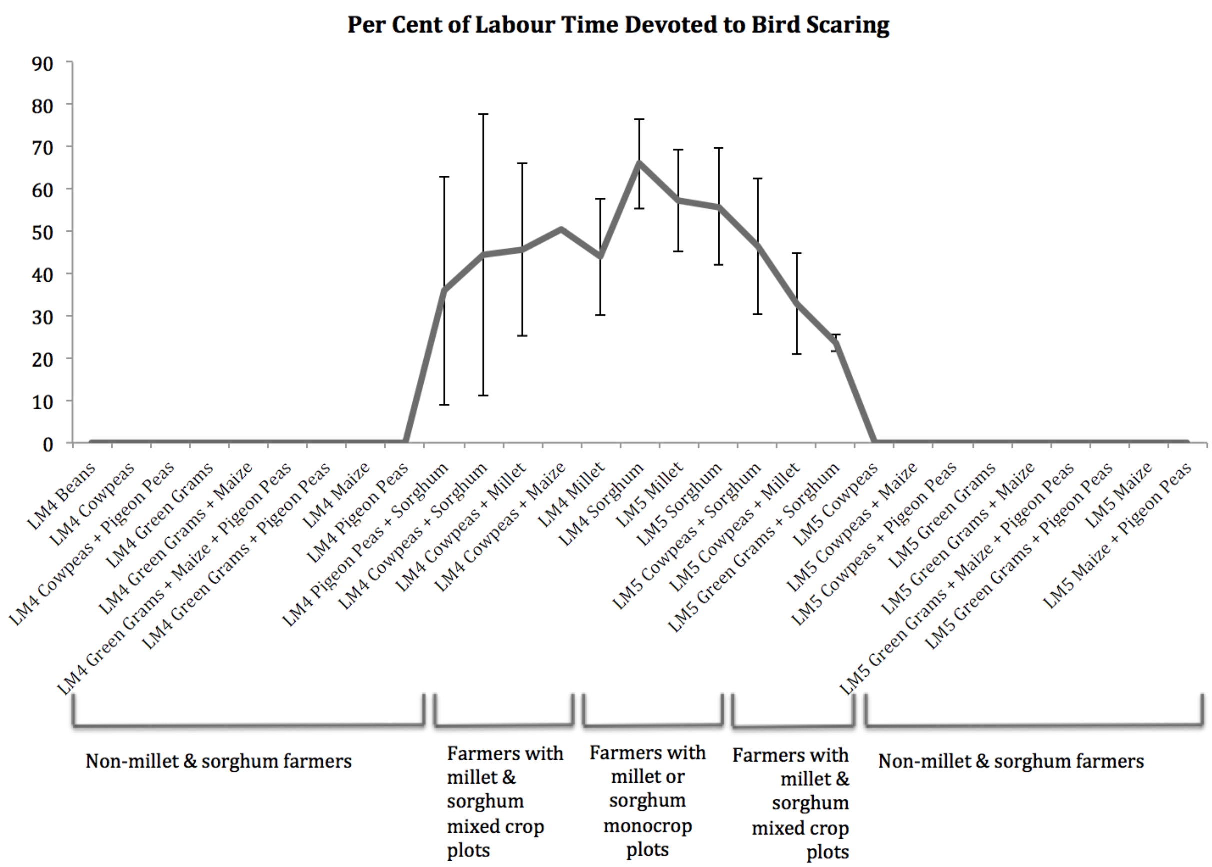


Figure 8 – Bird scaring as a percentage of total labour time.

Figure 8, above, illustrates the existing tensions between farmers' crop choice and labour allocation to bird scaring: almost no non-millet and sorghum farmers report scaring birds as a labour input; farmers with mixed crop plots containing millet and sorghum allocate 24-47% of all labour time to this activity; finally, across both zones, farmers with monocrop plots of millet and sorghum devote 43-66% of their labour time to scaring birds.

Next, we more closely examine the impact of bird scaring on labour intensity in our study area. From this point forward, only popular crops grown in monocrop plots are considered: cowpeas, green grams, maize, millet and sorghum. Examining monocrop plots in isolation allows us to more precisely determine the relationship between specific crops, labour intensity and bird scaring. Representing only 2% and 7% of plots in two LM4 villages, pigeon peas was dropped from the analysis. Similarly, beans were also dropped at this stage as only 2% of plots in one village (LM4 Kanyange) grew this particular crop as a monocrop. This provides a final sample size of 52 households and 162 plots (mean plots per household: 3.1, max: 9, min: 1, SD: 1.7). The mean plot size in the final population is 1 acre (SD: 0.91).

Figure 9 compares bird scaring as a percentage of total labour time devoted to bird scaring by select monocrop in Tharaka-Nithi.

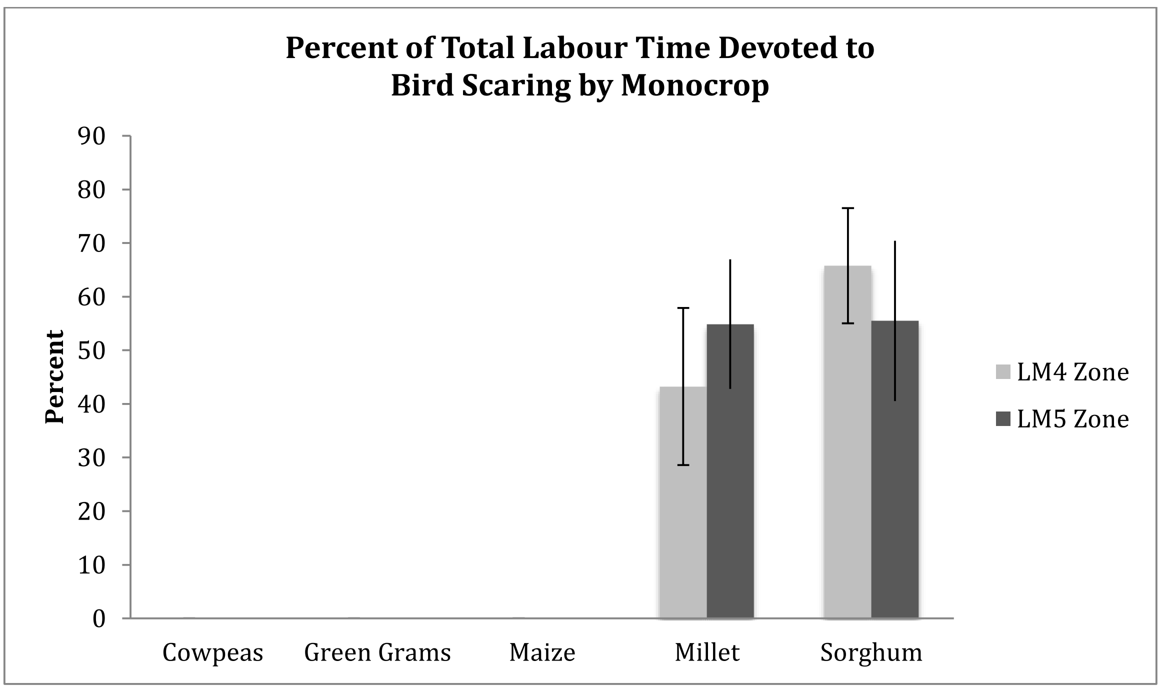


Figure 9 - Bird scaring as a percentage of total labour time for select crops within the study area.

Examining time spent bird scaring as a percentage of all other labour inputs, monocrop farmers of millet and sorghum, across both LM4 and LM5 zones, spend on average 43-66 per cent of all labour time on this activity. This amount of time is in stark comparison to monocrop farmers of green grams, cowpeas and maize who do not allocate any labour time to scaring birds from their plot. The results also show that 100 per cent of millet and sorghum farmers report bird scaring as a labour input, compared to 0 per cent of cowpeas, green grams and maize farmers.

Tables 16a and 16b outline the first and second most labour intensive inputs and revenue productivity of labour (RPoL), good season vs. bad season, for select crops in both LM4 and LM5 AEZs

(a) LM4 Agro-Ecological Zone in Tharaka-Nithi County						
Crop	Top Labour Input	Average Time Spent on Top Labour Activity (man-day/acre)	Second Most Intensive Labour Input	Average Time Spent on 2nd Top Labour Activity (man-day/acre)	Revenue Productivity of Labour (KSH/man-day) *Good Season*	Revenue Productivity of Labour (KSH/man-day) *Bad Season*
Cowpeas	Harvesting	5.9 (SD: 3.7)	First Weeding	4.6 (SD: 2.7)	454.99 (SD: 270.15)	136.16 (SD: 147.34)
Green Grams	First Weeding	7.1 (SD: 7.0)	Threshing	5.2 (SD: 4.1)	718.70 (SD: 464.42)	347.47 (SD: 353.13)
Maize	Planting	13.8 (SD: 26.4)	Threshing	12.8 (SD: 14.3)	910.71 (SD: 819.35)	133.34 (SD: 265.89)
Millet	Bird Scaring	51.4 (SD: 36.1)	First Weeding	14.5 (SD: 11.0)	296.89 (SD: 476.38)	95.31 (SD: 152.98)
Sorghum	Bird Scaring	81.8 (SD: 54.4)	Planting	7.9 (SD: 11.4)	272.19 (SD: 540.11)	181.33 (SD: 544.96)

(b) LM5 Agro-Ecological Zone in Tharaka-Nithi County						
Crop	Top Labour Input	Average Time Spent on Top Labour Activity (man-day/acre)	Second Most Intensive Labour Input	Average Time Spent on 2nd Top Labour Activity (man-day/acre)	Revenue Productivity of Labour (KSH/man-day) *Good Season*	Revenue Productivity of Labour (KSH/man-day) *Bad Season*
Cowpeas	Harvesting	10.5 (SD: 2.5)	Storage	5.7 (SD: 3.1)	321.29 (SD: 171.45)	195.09 (SD: 275.95)
Green Grams	Harvesting	7.6 (SD: 1.8)	Planting	7 (SD: 5.6)	501.95 (SD: 250.12)	154.02 (SD: 162.41)
Maize	First Weeding	14 (SD: 1.7)	Threshing	11 (SD: 5.4)	295.43 (SD: 100.20)	45 (SD: 90)
Millet	Bird Scaring	64.3 (SD: 39.7)	Harvesting	12.5 (SD: 8.8)	151.11 (SD: 77.37)	68.21 (SD: 89.10)
Sorghum	Bird Scaring	75.4 (SD: 50.3)	Harvesting	14.8 (SD: 4.5)	112.87 (SD: 46.36)	34.72 (SD: 42.27)

Table 16 – The first and second most labour intensive (man-day/acre) inputs and revenue productivity of labour (KSH/man-day), good season vs. bad season, for select monocrop plots within Tharaka-Nithi's LM4 (a) and LM5 (b) Agro-Ecological Zones.

For cowpeas, green grams and maize, the top two labour inputs consisted of traditional, labour intensive inputs for smallholder farming, notably harvesting, planting, weeding and threshing. Bird scaring, however, dominates labour time for farmers of millet and sorghum. Comparing time spent bird scaring versus time spent on the second most labour intensive activity for producers of millet and sorghum, we find that farmers of these crops spend between 5.1 and 10.4 times as long scaring birds from their land as they do on any other single labour activity.

The cost implications of spending more time scaring birds manifest when comparing the revenue productivity of labour across crops. In a good season, across both LM4 and LM5 Agro-Ecological Zones, the combined average revenue productivity of labour for farmers of millet and sorghum is significantly lower (LM4 conditions: $t(92)=2.99$, $p=0.00$; LM5 conditions: $t(107)=6.36$, $p=0.00$) than for farmers of all other crops. Non-bird scaring farmers experience a revenue productivity of labour on average 2.4 and 2.8 times greater in the LM4 and LM5 zone, respectively. In a bad season, a similar trend emerges - non-millet and sorghum farmers experience an RPoL 1.5 and 2.6 times greater than bird scaring farmers in the LM4 and LM5 zone, respectively. No significant difference, however, was found among LM4 bad season variables (LM4 conditions: t(92)=0.97, p=0.37; LM5 conditions: t(107)=3.06, p=0.028).

In summary, we conclude that varieties of millet and sorghum are of preference to birds in Tharaka-Nithi's semi-arid Chiakariga, Matiri and Nkarinia villages. Crop raids by birds are a significant challenge for mixed and monocrop plot farmers of millet and sorghum in our study area, 100% of which allocate labour time to scaring birds. Farmers with monocrop plots of millet and sorghum in the study area devote 43-66% of all labour time scaring birds from their plot, spending between 5.1 and 10.4 times as long scaring birds from their land as they do on any other labour input. Finally, this great labour cost suggests a lower revenue productivity of labour for bird scaring farmers in good seasons across both Agro-Ecological Zones and in LM5 bad seasons.

6.5 Rational Farmers?

The previous section focused on the impact of birds on farmers' factors of production, in particular labour. However, the analysis of this tragedy can also be enlightened by a discussion on externalities. Theoretically, how would conditions appear if farmers were not to scare birds at all, instead allowing pests to consume millet and sorghum from their plot undeterred? Extrapolating from our 'per cent of labour time devoted to bird scaring' curve plotted in Figure 8, we posit that under equilibrium conditions, with no bird scaring (zero intervention), farmers' crop loss to birds throughout a community should logically follow an approximate Gaussian distribution, as detailed in Figure 10a. In particular, in semi-arid Kenya, non-millet and sorghum farmers experience zero loss to birds; subsequently, depending on the proportion of land dedicated to the desirable crops, farmers with mixed crop plots containing millet and sorghum experience a range of losses; finally, farmers with monocrop plots of millet and sorghum suffer the greatest loss to birds.

The act of bird scaring by each individual farmer disrupts the normal distribution of loss, shifting the negative cost of pests from farmer to farmer as birds take flight and travel from plot to plot (Diagne et al., 2013). This transfer of costs creates a 'ripple effect' – a fluid and dynamic scenario in which costs are continuously shifted around the community from one individual farmer to another, as graphically presented in Figure 10b. Individual level technic adoption (Mumford, 1964) and increased labour allocation further perpetuate this cost-shifting, 'ripple effect'. Individual farmers can purchase and install nets, high-pitch speakers or other capital-intensive, technological measures to limit the impact of birds. Similarly, labour endowed farmers may allocate greater time to the issue, often through high opportunity cost, in-family labour recruitment. While economically 'efficient' from a self-interested perspective, this scenario is surely inequitable – farmers with the means to introduce capital and labour intensive solutions 'win', while further exposing vulnerable farmers to risk.

Individual intervention by farmers fails to achieve a so-called Pareto optimal state, "… a feasible situation, usually in terms of the allocation of goods and production factors, for which there exists no other feasible situation that is weakly preferred to it by all agents" (Verhoef, 2002: p198). Following Pareto optimality, therefore, any change that makes at least one member of society better off, without decreasing the welfare of another, is considered an improvement. Individual farmer intervention to crop raids by birds offers a bizarre 'momentary Pareto-optimal' situation – short-term, local unstable solutions. Waiting on their land for a bird crop raid, one farmer of millet or sorghum will successfully scare birds from his or her property; during the period of flight, Pareto-optimality occurs as welfare is maximized across all farmers. This 'momentary Pareto-optimal' can last only as long as birds stay in the air – as soon as they land, costs are shifted to another farmer, wellbeing is reduced and the 'ripple effect' continues.

Through the lens of environmental and resource economic theory, this cost-shifting 'ripple effect' behaviour bears strong resemblance to a negative externality. In this context, we understand the supplier of the externality as the farmer of millet and sorghum, who effectively reduces crop raids on his or her individual plot without considering the impacts to their neighbor (Baumol and Oates, 1988) – this leads to the creation of a true negative externality (Verhoef, 2002). Raiding the land, birds shift down farmers' production function of millet and sorghum. However, once bird scaring takes place at the individual plot level, costs are then transferred to a neighbour as soon as birds descend elsewhere.

To alleviate the negative cost associated with an externality, ERE theory offers three policy prescriptions: (i) government intervention (command-and-control regulation), (ii)

Pigouvian taxation and (iii) Coasian bargaining. Let us theoretically examine the applicability of each policy for the case of bird scaring in semi-arid Kenya.

According to command-and-control, a government can address negative externalities by requiring or forbidding certain behaviours or activities – this option is chosen if the external costs to society outweigh the benefits to the supplier (Mankiw, 2014). At the heart of government regulation is the normalisation of technics (Mumford, 1964) internalising externalities, potentially encompassing two forms: an outright bird scaring ban, or bird extirpation. Introducing a ban on bird scaring would result in considerable crop loss for farmers of millet and sorghum, as birds would be undeterred from damaging plots. This strategy falls short in overcoming a significant barrier for achieving household food security under conditions of climate uncertainty as it fails to change the opportunity costs of agricultural production in semi-arid Kenya. Under this approach, the farmers' loss to birds curve would remain as seen in Figure 10a.

'Bird kill' - conducted either by affected farmers under the direction of government officers, or by government itself - also fails to address the central issue. In the near term, local extirpation reduces the agricultural threat posted by birds, ridding farmers of the pest from their land and quashing loss. In Western Africa during the 1950s, for example, explosives, bulldozers and flamethrowers were used to kill *Quelea* birds, focusing specifically on chicks and nests (Mallamaire, 1961). More recently, spraying of avicides, including parathion, fenthion and cyanophos, has been adopted as a means to destroy *Quelea* roosts and their colonies (Elliott, 1979; Manikowski, 1988). Following extirpation, the loss curve is shifted down due to the diminished avian population, as presented in Figure 10c. Do not be seduced, however, by extirpation's myopic loss curve. This 'top down', avicidal approach - although often proposed as a viable solution to Problem Animal Control (PAC)(Ruelle and Bruggers, 1982) - is an unstable, costly and unsustainable strategy for all members of the community in the long run. Aerial sprays and traps are both capital and labour intensive and necessitate a deep understanding of the area's agro-ecological and meteorological conditions (Elliott, 1979; Manikowski, 1988; Tracey et al., 2007). Specifically, attempts to kill birds are an endless task as pest birds have high population turnover and natural juvenile mortality rates (Tracey et al., 2007). Traps require constant relocation and upgrading to avoid habituation by birds (Mallamaire,

1961) and disrupt the natural ecosystem through frequent by-catch of non-pest unintended wildlife (Tracey et al., 2007). Similarly, while birds are a net-pest to farmers of millet and sorghum, some existence of birds is required in agro-ecosystems as they provide extensive regulating, provisioning, supporting and cultural services (Kronenberg, 2014). Furthermore, and leaving aside a utilitarian perspective with regards to birds, if agricultural land is considered an agro-ecosystem then all of the species that conform the community are required for its healthy functioning (Bruns, 1960; May, 1988; Matson, 1997; Wilsey and Potvin, 2000; Wenny et al., 2011). Native birds are both pests and beneficial predators (Bruns, 1960; Tracey et al., 2007), consuming an estimated 16 times more pest insects than beneficial insects (McGauley, 2004). This sentiment is best echoed by Benjamin Franklin, who notes:

> *"In New England they once thought blackbirds were useless, and mischievous to the corn. They made efforts to destroy them. The consequence was, the blackbirds were diminished; but a kind of worm, which devoured their grass, and which the blackbirds used to feed on, increased prodigiously; then, finding their loss in grass much greater than their saving in corn, they wished again for their blackbirds."*
> *(Franklin et al., 1853: p407)*

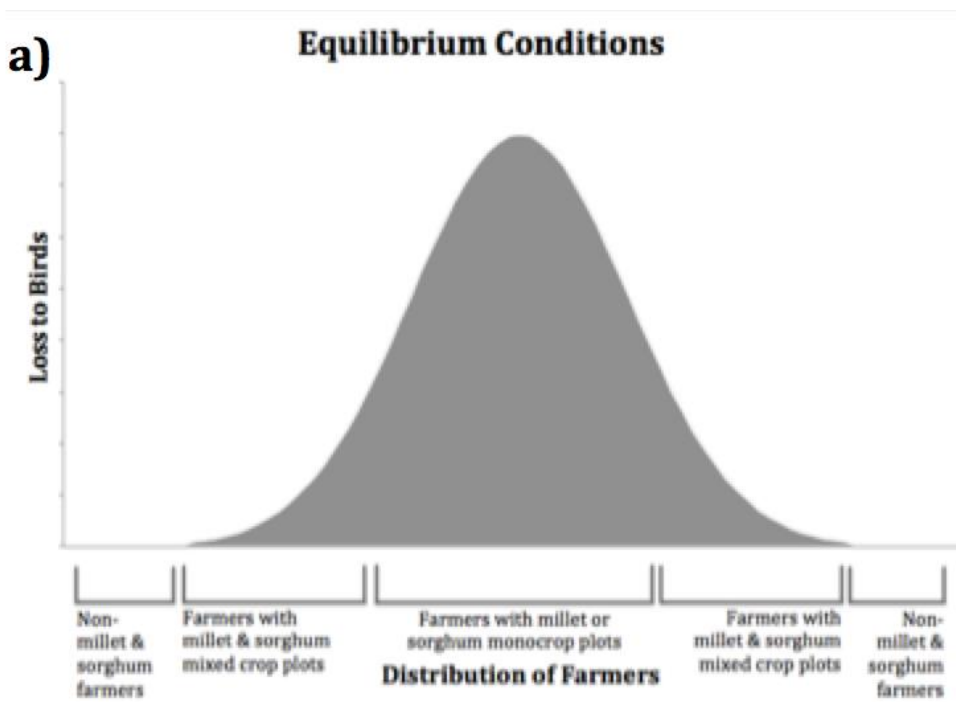
Government intervention takes away rights from farmers on if, or how to scare birds, impacting not only affected farmers but the population at large. Eliminating all birds from an area, command-and-control strategies produce inequitable, distortionary, cost-shifting effects. Non-millet and sorghum farmers, dependent on some level of birds for insect pest control, are indirectly punished, creating an externality in itself and shifting costs to those farmers. Inevitably, command-and-control is a costly strategy in the long run, both ecologically and for all members of the community, through direct and indirect effects.

The second ERE policy for externality internalisation involves incentives and disincentives. For instance, corrective taxes (disincentives) aimed to deal with negative externalities are Pigouvian taxes, set to equal the difference between the private cost (cost to the supplier) and the social cost (the aggregate cost to the receptors). Introducing a tax on a negative externality-imposing activity increases the equilibrium price, therefore sending a disincentivising future price signal. Following this policy prescription, governments could impose a tax on bird scaring farmers to deter their cost-shifting behaviour. Alternatively, government could deliver a positive incentive by compensating those farmers allowing crop raids on their lands (Agarwala et al., 2010). Setting an *efficient* incentive or disincentive rate, however, would be impossible in practice, as there is no way to precisely determine exact utility loss to each receptor attributed directly to his or her supplier as costs are continuously shifted around the community as birds take flight. Furthermore, this approach would present significant bureaucratic challenges, as government agencies would require the implementation of 'bird tax officers' in rural Kenya. Under an incentive or disincentive scenario, equilibrium conditions remain (Figure 10a)

Finally, based on the practice of private bargaining and negotiation among agents, Coasian bargaining is the third prescription for externalities. In his seminal 1960 work, *The Problem of Social Cost,* Ronald Coase argued that given (i) well-defined and enforceable property rights, (ii) economic rational actors and (iii) low transaction costs, private parties can solve the problem to externalities (Coase, 1960). Furthermore, through Coasian bargaining, both the supplier and receptor will benefit from negotiations on the size, scope and imposition of the externality (Verhoef, 2002), inevitably resulting in an efficient allocation of resources (Mankiw, 2014). In the context of bird scaring, however, this approach once again faces challenges and is insufficient in effectively solving our bird scaring case, as Coase's three assumptions are not met. First, while property rights may be well defined and enforceable (in our study, farmers mapped their delineated plots), birds do not acknowledge nor respect human property right assignation. Second, farmers cannot be considered only self-interested, economic rational actors, but sometimes exhibit "*other-regarding preferences*" (Gsottbauer and van den Bergh, 2011: p227). For instance, individual utility accounting might not be the hegemonic rationality under which decisions are taken in conditions of close-knit communities dealing with environmental impacts (Vatn, 2005; Ariely, 2010). Third, Coasian solutions result in high transaction costs for all farmers. An example best explains the latter. Imagine Farmer A and Farmer B, two Kenyan smallholders of millet and sorghum plagued by *Quelea* raids, each devoting the lion's share of labour time to scaring birds. Under a Coasian framework, Farmer A could pay Farmer B each time birds are evicted from plot A to plot B, and Farmer B will provide compensation when the birds return. Alternatively, Farmer A may pay Farmer B to never scare birds.

Farmer B, therefore, is compensated for his or her crop loss, and Farmer A will experience fewer bird infestations. This negotiation scenario, however, is largely infeasible. With dozens of millet and sorghum farmers in each community, highly-coordinated, costly farmer groups would be required to determine who pays who, or to regulate which farmers must not scare birds each season. Additionally, an efficient compensation rate is impossible to determine as there is no way to concretely calculate exact monetary or crop loss to birds resulting from one farmer's scare (externalising) action. To effectively and efficiently implement such framework, continuous monitoring and evaluation would be necessitated, involving investigative agents comically following birds around the community, examining their appetite at each plot. Inevitably, Coasian bargaining will fail to bring about a socially optimal level of so-called external cost as efficient and effective negotiations are not within reach. Following a failed Coasian effort, the 'ripple effect' remains, as graphically presented in Figure 10b.

Focusing largely on technological solutions, property right assignation, self-interest and individual utility calculation, all three ERE prescriptions for externality assessment are inadequate for our bird scaring case at hand.



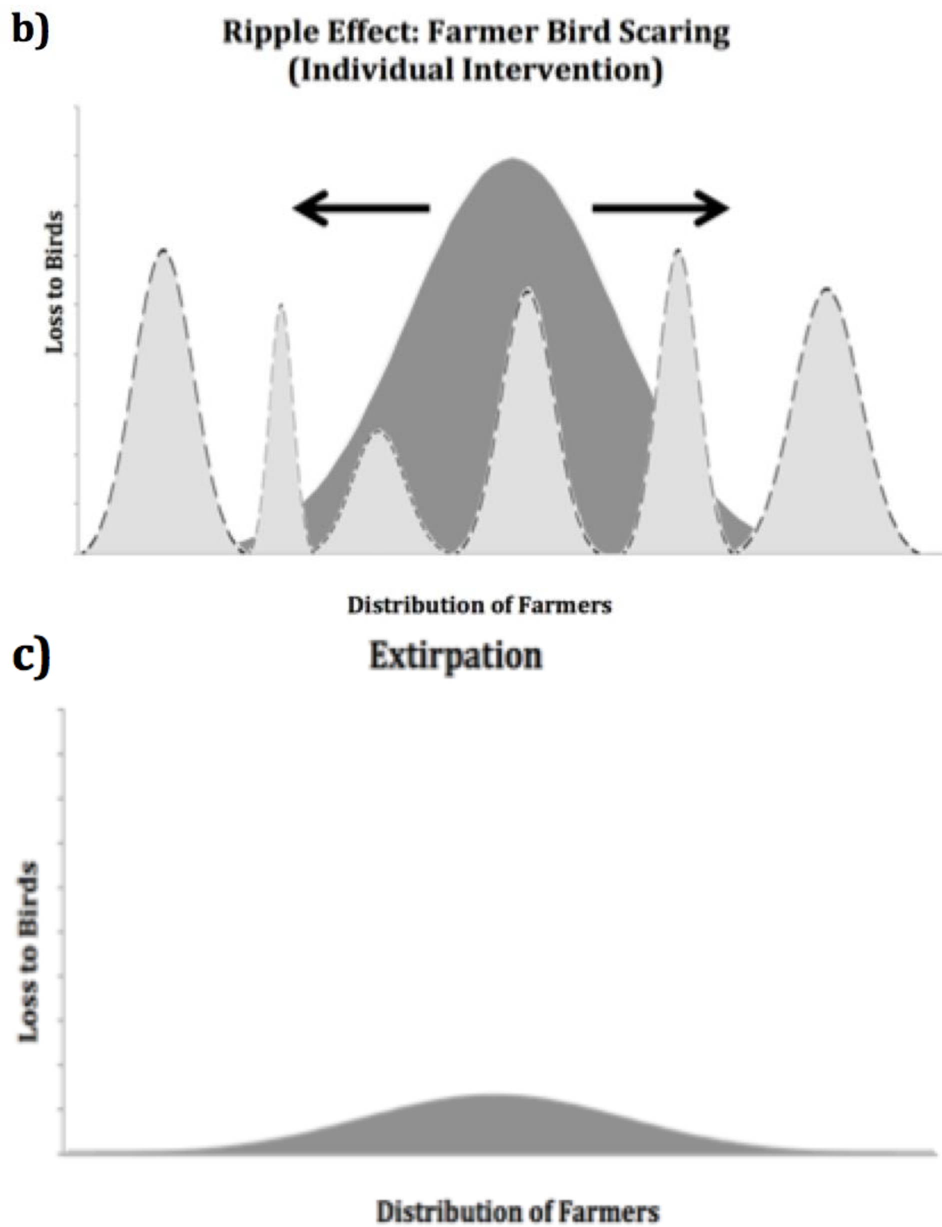


Figure 10 - a) Farmers' loss to birds under equilibrium conditions.
b) Farmers' loss to birds with the 'ripple effect' - farmer bird scaring (individual intervention).
c) Farmers' loss to birds under extirpation (command and control / government intervention).

6.6 From Cost Shifting to Deliberate Cost Distribution

Inevitably, our 'ripple effect' discussion presents nothing new – merely a theoretical application (and microeconomic example) of Kapp's pioneering work on social cost and cost-shifting. Contrary to neoclassical value theory which regards "social losses as accidental and exceptional cases" (Kapp, 1963: pxi), Kapp shows that social costs are a frequent and highly important part of the economic system (Kapp, 1963). Acting rationally, farmers gauge market conditions, including limited labour inputs and opportunity costs, to externalise the cost of birds to neighbours. Briefly ridding birds from his or her land, bird scaring by individual farmers awards a positive utility gain to the farmer – the cost of such action, however, is distributed among the wider population. Inevitably, pest control is a public goods issue (Chambers et al., 2010; Diagne et al., 2013) - what Norgaard (1976: p24) describes as a 'social problem': "Unlike most farm production problems, there are important relationships between farmers. The… management practices of one farmer can beneficially or detrimentally affect … the success of the management practices of other farmers". In our case, the bird scaring practices of Farmer A directly impact Farmer B's production function.

Failing to appreciate the social nature of pest management, ERE prescriptions all fail due to misplaced scale and focus. Community-wide, inherently social problems such as pest management cannot be adequately addressed without considering the effects to society as a whole. Much like Hardin's infamous discussion of 'no technical solution problems' (Hardin, 1968), the tragedy of bird scaring cannot be solved through technological interventions alone – at the heart of the problem lies human behaviour. Understudied and largely under implemented (Norgaard, 1976), collective action – decisions in pursuit of a common goal undertaken by a group at the maximum scale in which coordination is achievable - represents a move beyond utility-oriented self-interest. An effective and feasible strategy to govern common resources, collective action allows nurtured shared values and the simultaneous pursuit of individual interests (Lee, 2003). Through a collective action approach - including community-wide planting schedules in line with *Quelea* migration patterns (Elliott, 1979), strategically placed plot level barriers (nets, fencing etc.) and coordinated bird chasing (deterring actions and noises) (Osborn and Park, 2002; Hedges and Gunaryadi, 2010; Diagne et al., 2013) - farmers can minimise and equitably share the cost of bird raids. Additionally, the upkeep of a 'feeding source' plot, a collective pest management 'investment' field dedicated to the cultivation of millet and sorghum where no bird scaring is undertaken, will ensure the regional bird populations remain satisfied without impact to farmers' production function nor other pest management collectives elsewhere. Ultimately, collective action allows transaction costs and welfare-losses to be shared evenly among affected households – strategically halting the cost-shifting 'ripple effect' through deliberative cost-distribution. Capturing this sentiment, Norgaard argues that farmers who act individually "… will equate their own incremental costs with their own incremental returns. If each farmer would also consider the benefits or costs imposed by his pests and management practices upon the other farmer, their collective profits can be greater" (Norgaard, 1976: p24). With the 'ripple effect' eliminated, collective action both shifts down and flattens but not eliminates the 'loss curve', increasing overall social wellbeing and eliminating a barrier to the greater adoption of HVTCs. Farmers' loss to birds under a collective action approach is graphically presented in Figure 11.

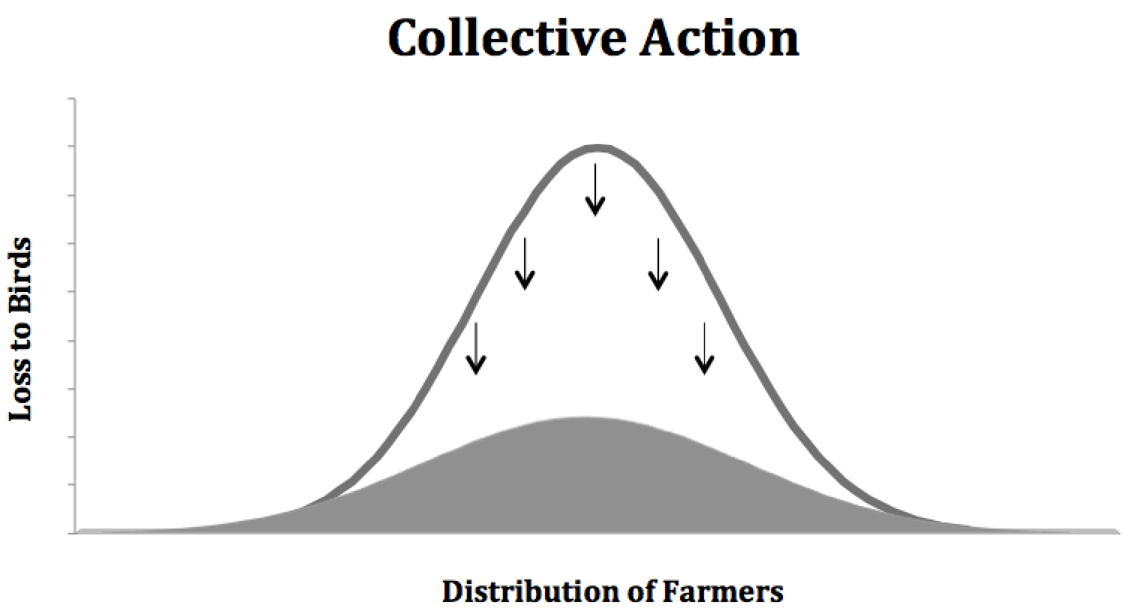


Figure 11 - Farmers' loss to birds through collective action.

Collective action powerfully internalises the context-specific complexity of development interventions by focusing not on singular technological prescriptions adopted by one individual or community, but instead on deliberate, organised farmer best-practices constructed democratically from within. Inevitably, collective action excels where Coasian bargaining falls short. Utility is calculated at the community and not the individual level – both positive utility gains and negative losses are shared – taking into account the limited self-interest and "*other-regarding preferences*" of agents involved (Gsottbauer and van den Bergh, 2011: p227). Changing the boundary at which the externality is assessed additionally challenges human property-right assignation in the light of ecological boundaries – bird scaring is understood as a common shared practice required to adequately manage an agro-ecosystem. This statement is once again reminiscent of Kapp, who describes the need for social cost to be calculated as a factor of doing business (Kapp, 1963).

Social capital formation and community-wide coordination are the greatest challenges associated with the collective action approach to bird scaring, including the institutional capacity to develop and maintain village-wide agreements vis-à-vis coordinated farm planning. Without organisation among farmers, individual agents have no incentive to undertake collective action (Norgaard, 1976; Ostrom, 1990). The costs associated with collective action, including the establishment of farmer groups, determining relationships and rules and on-going management costs must be lower than the benefits associated with collective bird scaring, otherwise there will be no net gain (Norgaard, 1976). Furthermore, "collective action is more likely to take place if there is a clear understanding of the interrelationships, if all parties can benefit without an elaborate compensation mechanism, if and a [*sic*] suitable institution for decision making and enforcement already exists" (Olson, 1965 in Norgaard, 1976; p26). The FAO's community Integrated Pest Management (IPM) programme presents a clear entry point for the integration and formalisation of collective bird scaring in semi-arid Kenya. "A strategy to institutionalise IPM at the community level" (FAO, 2002: p49), community IPM aims to "sustainably enhance" the lives of farmers through learning, experimentation and organisation (Elske et al., 2002). Using the teacher-trainer farmer field school (FFS) model, farmers are encouraged to establish organisations to resolve local problems and improve the livelihood of local farmers, conduct IPM programmes, enlist local institutions, promote sustainable agriculture and employ egalitarian practices in problem-solving and decision-making processes (FAO, 2002). In addition to the benefits associated with decreased bird scaring - including greater HVTC adoption and household resilience, increased time for 'next best' income generating and social activities (Chambers et al., 2010) and higher education attainment for children - the community IPM model for bird scaring may lead to knowledge transfers and positive spillover effects resulting from collective, coordinated agricultural management and community organisation (Pretty and Ward, 2001). Further research on farmer group institutional capacity and the community IPM model is required to understand this potential entry-point and the associated spillover effects.

7 Conclusion

Examining agro-economic data from eighteen villages in Machakos, Makueni and Tharaka-Nithi Counties, I set out to advance the knowledge of smallholder agriculture in semi-arid Kenya with the overall goal of improving food security in the region. These objectives were fulfilled by broadly following van Mil et al.'s (2014) three-stage systematic approach to addressing complex problems in agriculture and food systems. (i) *Describe the specific problem conceptually, based on observation, and offer potential intervention strategies*; overviewing current literature and policies on food security, focusing on arid and semi-arid lands in Kenya, chapter two delineated the harsh and frail backdrop against which farmers in the region subsist. Furthermore, using existing literature and anecdotal evidence for hypothesis testing, chapter four presented a multiple and logistic regression analysis of the dataset, exposing the entrenched frailty of smallholder agricultural systems. (ii) *Harvest information on each level within the complex system;* using stage one's statistical analysis, logical, data-based inferences were made vis-à-vis how agricultural policy in Kenya can better contribute to food security for smallholder farmers, drawing heavily on the FAO's climate-smart agriculture framework. (iii) *Estimate the effectiveness of interventions*; transitioning to a theme of complexity, I offered a theoretical (and at times humorous) analysis of one particular barrier to the greater adoption of High Value Traditional Crops, a CSA practice, demonstrating the inherent complexity of even the most seemingly-simple development intervention. This approach, through the 'lens' of ecological economics, more broadly challenged the way in which environment and resource economics views, addresses and prescribes *so-called* externalities.

Three key findings arise from our regression analysis. First, Agro-Ecological Zone is a determinant of labour productivity and the revenue productivity of labour for smallholder farmers in the study area villages of Machakos, Makueni and Tharaka-Nithi County. Farmers in the Lower Midlands 4 zone, characterised by lower mean temperature and higher annual precipitation, are more likely to 'break even' in good and bad seasons than farmers in Lower Midlands 5. Second, despite anecdotal evidence provided by farmers, monocrop plots outperform mixed crop plots in the study area, offering a higher probability of breaking even in both good and bad seasons and lower cost and labour intensities. Finally, within the study area, High Value Traditional Crops, notably green grams and millet, increase farmers' likelihood of breaking even in both good and bad seasons, and sorghum, too, has a role to play.

While rigorous statistical methods were adopted to carefully peel away the layers of frailty in smallholder agriculture and describe the specific problem based on observation (van Mil et al., 2014), the most important finding from this thesis can arguably be attributed to descriptive statistics: across both Agro-Ecological Zones of the study area, mean economic rent is negative in both good and bad seasons and only half of all plots broke even during a good season and 19 per cent in a bad season. Inevitably (and quite inadvertently), descriptive statistics provided the ultimate starting point for this thesis, illuminating the frailty of smallholder agricultural systems and forcing myself to, from a statistical perspective, harvest which factors hinder or assist farmer's agricultural productivity.

In a preliminary, sweeping attempt to address a profoundly frail system whereby farmers, in the best possible scenario, are only as successful as a coin toss, I present a climate-smart agriculture model of resilience for smallholder agriculture in semi-arid Kenya – offering potential intervention strategies based on observation (van Mil et al., 2014). Through small-scale 'mosaic monocropping' and greater adoption of High Value Traditional Crops, farmers can sustainably increase agricultural productivity and incomes while building resilience at the household level. This resilience model is extended to the community scale, where shared yield for consumption, collective pest management and microinsurance can provide a safety net in times of drought and poor harvest. Finally, at the National scale, the Kenyan government must continue its support for smallholder agriculture, materialising this agenda through integrating private, common and public good provision.

Using data to expose the frailty of the system and its underlying dynamics, this statistical analysis has, inevitably, done the 'easy bit' of food security research. CSA policies are recommended by questioning why significant trends exist where they do and, equally important, why insignificance emerges. The true challenge of research, however, involves overcoming the barriers to achieving these policy aims and 'harvesting' information on each level of the intervention (van Mil et al., 2014). This is the union of frailty and complexity: while this data analysis readily exposes the frailty of the system, an exploration into each intervention uncovers the inextricable complexity of the system itself. With such a diverse array of intervention points, each with an overwhelmingly complex series of underlying factors, this thesis ends somewhat irresponsibly - we present a variety of climate smart interventions but dig deeper into only one of them: bird scaring by farmers of millet and sorghum as barrier to the greater adoption of HVTCs. Specifically, we demonstrate that varieties of millet and sorghum are of preference to birds in the region; all farmers of these crops in the study area reported bird scaring as a labour input, devoting on average 24-66 per cent of all labour time to this activity – a stark contrast to farmers of all other crops, almost zero per cent of which reported scaring birds. This case study provides a window for analysing farmers' behaviour with respect to pests, rather than bird populations themselves. Waiting on their plot for birds, farmers scare away the pests to mitigate the negative loss associated with a crop raid. Subsequently, birds take flight, landing on a neighbour's plot for their next feast and the whole process is repeated. Acting individually, this scenario creates a 'ripple effect' whereby the negative costs are continuously shifted (externalised) around a community - individual wellbeing is maximised only so long the birds stay in air. In the most wretchedly absurd fashion, *The Tragedy of Bird Scaring* demonstrates the context and geographic-specific complexity of agricultural interventions – while it may be economically, politically and socially agreeable to promote the adoption of High Value Traditional Crops, doing so, as with any intervention, changes the dynamic of the system and the implications of these manipulations must be understood and carefully considered.

Inevitably, the tragedy of bird scaring challenges the way we view and address the environment in our current economic paradigm. Utility-loss calculations and monetary valuation efforts for ecological and environmental phenomena are idealist at best, as there is no way to accurately attribute direct wellbeing loss - the attainment of an 'efficient' level of taxation or compensation is truly infeasible. Addressing so-called externalities with individual, self-interested solutions fails to improve overall wellbeing, instead promoting cost-shifting practices and perpetuating existing inequities. At the community scale, through collective action to address crop raids by birds, farmers in each community can advance from a paradigm of cost-shifting to one of deliberate cost-distribution, halting the 'ripple effect' through coordinated scaring, planting schedules and community IPM. From birds to pollutants, collective action is an effective, overlooked and understudied approach to address the challenges facing our planet. Understanding these challenges not as so-called externalities but as a by-product of cost-shifting behaviour to be addressed through coordination, the boundary at which we address complexity of the system changes. If farmers in Kenyan villages were to succeed in scaring away all birds from their community, the costs will be shifted to the next village. If addressed at the national scale, Kenya would simply externalise all costs to Tanzania, Uganda, Somalia, South Sudan and Ethiopia. In this context, the question is raised, what is really 'external' about externalities?

By exposing frailty but only addressing one element of complexity, this thesis inevitably opened more doors than closed, asked more questions than answered. This, however, is the patient and meticulous nature of development and intervention research - there can be no 'silver bullet'. In West Africa during the 1950s, as previously mentioned, explosives, bulldozers and flamethrowers were used to address *The Tragedy of Bird Scaring* with disastrous ecological implications (Mallamaire, 1961). Similarly, an unwavering support for maize by Kenyan Government officials and international organisations in recent decades conveys the same story. Focusing narrowly on supply chains, market prices and potential yield gains through improved varieties, this unfaltering approach entirely overlooks the water-intensity of the crop, it's weakness in drought years and it's incompatibility with arid and semi-arid land, gravely misleading already-vulnerable smallholders - our probability analysis unveils the bleak truth behind this policy. More recently, some development practitioners and authors have called for a revolution in smallholder agriculture away from subsistence to commercial farming, eliminating poverty through growth and agri-business (Gallup et al., 1998; Mellor, 1999; Thirtle et al., 2003; Wilson and Wilson, 2006; Weinberger and Lumpkin, 2007; Government of the Republic of Kenya, 2010; Moyo, 2010). Admirable in their idealistic vision, 'silver bullet' approaches fail to recognise complexity, implicit and explicit power dynamics and do not consider the abundance of inherent feedback loops (Mumford, 1964; Chambers, 1995; Goetz and O'Brien, 1995; Blowfield and Dolan, 2010). While politically appealing, the terms 'commercial' and 'subsistence' disingenuously obfuscate what actually happens in the dirt: in a year of bountiful harvest, farmers can produce enough to feed their families and sell the excess; in poor years, farmers are hungry not because they have sold their crop, but because the land did not provide. In this sense, farmers are commercial farmers one year and subsistence farmers the next – any plan to turn smallholders into 'businessmen' must recognise these inherent truths, no matter how unappetising this is for campaign signs or glossy annual reports. The truth is, a market-based approach, just like maize-promotion, flamethrowers or any singular intervention strategy cannot solve the food security challenge in semi-arid Kenya, not because they are the wrong intervention, but because each cannot be the *only* intervention. 'Silver bullets' fail to provide stability in a complex system, overlooking time and context specificity, local norms, ethics and generational knowledge. Reductionist strategies like this can work only when placed within a mosaic of interventions - a complex systems approach - that factor in consensus building, democratic norms, the need for sustainability and a plethora of other cultural and context-specific characteristics of the food security challenge that integrate different levels of detail and draw upon different disciplines (van Mil et al., 2014); with the advent of climate change which increases the risk, instability and unpredictability of each intervention (Morton, 2007; FAO, 2013a), the importance plural-thinking has never been so critical. Inevitably, a climate-smart agricultural framework should not only be solely about technology, economics or production, but is ultimately about changing farmers' practices and influencing behaviour at the individual, community and National levels – collective action provides a powerful cornerstone tool for achieving these aims.

With the challenge of food security seemingly more insurmountable, frail and complex now than the first page of this thesis, the question emerges: what's next for food security in semi-arid Kenya? The answer can come only through the deliberative process of research. Slowly, layer by layer, peeling away the sheets of unknown for each climate-smart intervention, chipping away at complexity through multi-disciplinary, multi-stakeholder, inclusive research, rooted in democratic technics (Mumford, 1964). Research of this nature is not singular, monolithic nor isolated to one period in time, but takes into account the dynamic nature of complexity by repeatedly readdressing the same 'solved' issues at future time points to ensure that previously prescribed interventions remain appropriate to the (inevitably-changed) system. This will involve data analysis and deliberation with farmers to scale up the interventions we do know work and, crucially, seeing why others do not. One by one, checking off all of the unknowns regarding each barrier to their greater adoption, each barrier to food security. This is the inherent beauty of research: complex systems, overwhelming challenges and precise deliberation for further knowledge development.

8 Analytical Appendices

8.1 Appendix 1 – Research Ethics Board (REB) application for Enhancing Ecologically Resilient Food Security through Innovative Farming Systems in the Semi-Arid Midlands of Kenya

McGill

Research Ethics Board (REB)
Faculty of Agricultural and Environmental Sciences
Application for Ethics Approval for Human Subject Research

Respond directly on this form below each question. Do not delete the text under the headings.
Do not omit or reorder any questions. Answer each question.
(more information at www.mcgill.ca/macdonald/research/compliance/human)

Complete form and submit to Chair, REB – FAES c/o the Macdonald Research Office, Raymond Bldg. R3-032.
(For undergraduate class projects, see section at bottom)

Project Title: Enhancing Ecologically Resilient Food Security through Innovative Farming Systems in the Semi-Arid Midlands of Kenya

Principal Investigator: Dr. Gordon Hickey
Dept: Natural Resource Sciences
Phone #: 514-398-7214
Fax #: 514-398-7990
Email: gordon.hickey@mcgill.ca

Mailing Address (if different than Dept.):

Status:		**Type of Research:**	
Faculty X	Master's Student ☐	Faculty Research X	Independent Study Project ☐
Ph.D. Student X	Undergraduate ☐	Thesis X	Course Assignment (course name and #) ☐ ________
Postdoctoral Fellow	Other (specify) ☐	Honours Thesis ☐	Other (specify) ☐

Faculty Supervisor (for student PIs): Email:
Co- Investigator(s) (list name/status/affiliation): All project team members are associated with McGill University

Researcher	**Title**	**Area of research expertise**
Bernard Pelletier	Research Associate	Knowledge integration, Agro-ecosystems, Africa (Malawi, Ghana)
Leigh Brownhill	Research Associate	Kenya, Gender, Institutions, Community development, Political economy
Timothy Johns	Professor	Kenya, Nutrition, Ethnobotany, Agrobiodiversity
John Galaty	Professor	Kenya, Land tenure, Pastoralism, Anthropology
Nicolas Kosoy	Assistant Professor	Ecological economics, Ecosystem services, Economic institutions,
Jim Fyles	Professor	NRM, Soil nutrient cycling, Knowledge networks,

(Updated October 2009) 1/65

		Institutional partnerships
Elena Bennett	Assistant Professor	NRM, Ecosystem services, Resilience, Adaptive management
Colleen Eidt	Graduate student (PhD)	Policy and institutions. Supervisor (Gordon Hickey)
Stephen Moiko	Postdoctoral fellow	Land tenure, socio-economics. Supervisor (John Galaty)
Patrick Cortbaoui	Graduate student (PhD)	Economics. Supervisor (Nicolas Kosoy)
Purity Karuga	Graduate student (PhD)	Environment and NRM. Supervisors (Elena Bennett & Jim Fyles)
Megan Dilbone	Graduate student (PhD)	Nutrition and health. Supervisor (Tim Johns)
Stephanie Shumsky	Graduate student (MSc)	Policy and institutions. Supervisor (Gordon Hickey)

For funded research, list all funding sources for this project and project titles (if different from the above). Indicate the Principal Investigator of the award if not yourself.

Awarded: IDRC/CIDA Canadian International Food Security Research Fund # 106510-002
Pending:

Principal Investigator Statement: I will ensure that this project is conducted in accordance with the policies and procedures governing the ethical conduct of research involving human subjects at McGill University. I allow release of my nominative information as required by these policies and procedures.

Principal Investigator Signature: ______________________________ Date: _________

Faculty Supervisor Statement: I have read and approved this project and affirm that it has received the appropriate academic approval. I will ensure that the student investigator is aware of the applicable policies and procedures governing the ethical conduct of human subject research at McGill University and I agree to provide all necessary supervision to the student. I allow release of my nominative information as required by these policies and procedures.

Faculty Supervisor Signature: ___________________________________ **Date**: _________
(for student PI)

Undergraduate Class Projects: REB review is not required if the surveys, questionnaires and/or results will remain in the classroom. The review of these applications is delegated to the Unit's Head. Further to approval, it is required that you submit one duly approved copy to the Chair, Research Ethics Board – FAES c/o Macdonald Research Office.

Signature: ___________________________________ Date: _____________________

Name Chair/Director of Dept./School:

1. Purpose of the Research

Describe the proposed project and its objectives, including the research questions to be investigated (one page maximum). What is the expected value or benefits of the research? How do you anticipate disseminating the results (e.g. thesis, presentations, internet, film, publications)?

This project addresses broad questions of how agricultural researchers, extension workers and policy makers can more effectively reach the poorest farmers to sustainably address food security. New strategies are required to increase smallholder adoption of resilient farming systems - that is, *farming systems with the flexibility to deal with stresses and disturbances as a result of internal and/or external change, while retaining the same basic structure, capacity for self-organization and capacity to adapt to change*.

The 2007-2008 food crisis followed upon global financial collapse. In Kenya, it coincided with violent displacements after the 2007 election and the failure of rains for six seasons. This convergence of crises demonstrated that global environmental and economic changes, as much as local social and political challenges, impinge upon the food security of the poor. The magnitude of these problems is demonstrated by the rising numbers falling into poverty and hunger. Kenya government statistics show that the proportion of individuals living on less than US$1/day in the arid and semi-arid lands (ASAL) regions stands at 65%. In Makueni county, one of the three counties included in the project, poverty levels stand at 74%. Hunger and malnutrition have a particularly pressing impact on women and children. Gender inequalities in land distribution and decision-making power are further barriers to the success of food security initiatives.

The objective of the research is to raise farmer adoption of resilient farming systems by: (i) identifying appropriate robust and effective agricultural and environmental practices; (ii) identifying incentives and constraints to the adoption of these practices; (iii) assessing different 'adoption pathways' – or influences on adoption decision-making - among different households and farmer organizations; (iv) examining means of enhancing the adoption of appropriate agricultural technologies both within and beyond the project area; (v) assessing and enhancing local utilization of high value traditional crops (sometimes referred to as 'orphan crops') in fulfilling needs for both subsistence and income-generation and (vii) finally, contributing to the design of policies to enhance resilient farming systems for food security, livelihood creation and environmental sustainability in all of Kenya's ASAL regions and beyond. The set of research activities by the McGill team will thus build on field activities undertaken by KARI to promote and assess agricultural and institutional innovations to enhance food security in semi-arid Kenya.

The expected benefits of the research are two-fold. First, the research develops an already-existing partnership between McGill and the Kenya Agricultural Research Institute, which has been working for many years on the question of food security. The research aims to reveal new means of improving food security policy by suggesting ways of improving the mobilization of relevant knowledge for farmers, researchers and policy-makers. The second benefit of the research is to generate new knowledge about farmers' 'adoption pathways' and 'best practices' for resilient farming. These are relevant to policy in Kenya, international development aid policy in Canada and to a larger audience of farmers, researchers and policy makers in the East African region in particular. The project's 'scientific value added' lies in its integrated approach that assesses farmer 'adoption pathways.' It brings farmers' understandings and expertise into the process of developing resilient farming systems by giving local farmers a leading voice.

We intend to disseminate the results of this research in the following ways: (1) a panel presentation at McGill's October food security conference; (2) a special issue of a journal including a number of articles drawn from the results of this project; (3) newspaper reports in the Kenyan press; (4) a research note in KARI's newsletter and website; (5) a working paper; (6) 'in the field' notes and research reports on an open-access website dedicated to this project; (7) pamphlets and a poster series depicting research findings in the field, aimed at farmers and policy makers in Kenya as well as policy makers and aid professionals in Canada; (8) social media, such as a dedicated SMS text 'hotline' for communications among farmers, researchers and policy-makers; and (9) other conference presentations by team members as the opportunities arise.

2. Recruitment of Subjects/Location of Research

Describe the subject population and how and from where they will be recruited. If applicable, attach a copy of any advertisement, letter, flier, brochure or oral script used to solicit potential subjects (including information sent to third parties). Describe the setting in which the research will take place. Describe any compensation subjects may receive for participating.

Research activities will take place in the semi-arid Lower Midland agro-ecological zones (AEZs LM5 and LM4, 600-800mm rainfall) in seven Districts located in three Counties of Kenya's Eastern Province: Machakos, Makueni, Tharaka. Farmers in these AEZs typically combine crop (primarily food) and livestock production under conditions of only moderate intensity of land use, with some dependence on hunting and gathering. The Focal Research and Development Area (FRDA) will form the basic unit for the proposed research. FRDAs correspond approximately to the *Location* administrative units in the Kenyan system. In total, the seven Districts that are part of this study include sixty (60) FRDAs.

It should be noted that the suite of McGill research activities will be designed in the context of KARI participatory on-farm activities taking place in local communities across the study area. Of the 60 FRDAs included in the project, eighteen (18) will be purposively selected by KARI and the Ministry of Agriculture (MoA) for the establishment of Primary Participatory Agricultural Technology Evaluation (PPATE) sites, which will be used to demonstrate various agricultural cropping systems and soil and water management practices. In each of these 18 FRDAs, three different sites will host a PPATE on-farm trial for a total of 54 PPATE sites. Each PPATE site is under the responsibility of a farmer group (FG). Members of these FGs will play a key role in mobilizing community resources, supporting technology evaluation and the adoption of skills and appropriate technologies. Within the FRDA, the FGs will elect *Farmers Committees* which will be responsible for the day-to-day management of project activities.

For each of the 54 PPATE site, a number of FGs will then be selected to host Secondary Participatory Agricultural Technology Evaluation (SPATE) sites in which farmers will be invited to select technologies to be established on their own farms after visiting the PPATE site. The establishment of the SPATE sites will be done in October 2012. The selection of the FGs to be involved in the SPATE trials will be performed randomly from a list of existing FGs found in the area surrounding each PPATE site. About 5-8 FGs will be selected per PPATE site for a total of approximately 250-400 farmer groups. Each FG will include between 12-20 households.

A baseline household survey will be administered jointly by KARI and McGill following two distinct sampling strategies. First, a two-stage cluster sampling design where a number of *Sub-locations* (i.e., a administrative division of the *Location*) will be randomly selected as Primary Sampling Units (PSUs) followed by a random selection of households within each *Sub-location*. This strategy will be conducted for each individual District, which will be considered as strata in the sampling strategy. The second strategy will be to randomly select a number of households among those belonging to FGs participating in the PPATE and SPATE trials. The purpose of the first sampling strategy is to generate a sample that is representative of smallholder farmers in the whole study area. The purpose of the second sampling strategy is to provide information specific to farmers directly participating in the project, in order to monitor and evaluate the impact of project interventions. Focus group discussions and Participatory Rural Appraisal (PRA) activities will also be conducted by KARI and the MoA in the different FRDAs to gather data at the community level and promote discussions among community members on constraints and opportunities influencing their livelihoods.

Each research stream under the responsibility of McGill researchers will have its own set of research activities that will be described in more detail in the Appendices. These activities will use a mixture of interviews with key informants among smallholder farmers, extension workers and policy-makers, and focus group discussions to be conducted in the various FRDAs. Participants in these focus groups, PRA activities and key informant interviews will be identified through a participatory process involving meeting of farmers and researchers and some self-identification by farmers of those to take part in these research activities. The selection of communities and interviewees to be included in these research activities will vary with the different research streams. In some cases, research activities will be conducted with farmers and farmer groups directly participating in the PPATEs and SPATEs. In other cases, activities may be conducted with farmers, farmer groups and/or communities outside the FRDAs hosting the PPATEs and SPATEs. In all cases, however, procedures and guidelines to interact with farmers and local communities will be standardized and based on KARI's current approaches. For example, participants in focus groups will be served a snack or meal. For informants who are interviewed at their own homes, an alternative contribution of foodstuffs will be provided in lieu of a meal. No other form of compensation will be provided.

3. Other Approvals

When doing research with various distinct groups of subjects (e.g. school children, cultural groups, institutionalized people), organizational/community/governmental permission is sometimes needed. If applicable, how will this be obtained? Include copies of any documentation to be sent.

At this point, no other ethical approvals are required in terms of working with distinct groups of subjects. Because the project is implemented jointly with KARI, McGill researchers and students do not need a separate research permit from the Kenyan Government. KARI have established procedures to interact with local communities and authorities and smallholder farmers that will be followed by all researchers and students involved in this project. These guidelines will be written in a partnership agreement between KARI and McGill University that will be attached to our Memorandum of Understanding (under preparation). Note that descriptions of activities my McGill researchers provided in the Appendices also follow guidelines agreed upon by McGill and KARI. The Kenya Medical Research Institute (KEMRI), a partner in this project, has a formal ethical review process that will be followed for project activities in which they are involved. For example, the baseline household survey will be examined by their Ethical Review Board.

4. Methodology/Procedures

Provide a sequential description of the methods and procedures to be followed to obtain data. Describe all methods that will be used (e.g. fieldwork, surveys, interviews, focus groups, standardized testing,...)

This research project is built around the establishment by KARI and the MoA of participatory on-farm trials in which various crop varieties and agricultural management practices will be tested jointly by researchers and farmers. Prior to the establishment of these on-farm trials, a baseline study will be conducted to collect data on the situation faced by smallholder farmers prior to project interventions. These baseline activities will include focus group discussions, a household survey and the analysis of aerial/satellite images to assess land-use. Finally, an interdisciplinary team of McGill and KARI researchers will conduct an integrated assessment of the food security situation in semi-arid Kenya in order to have a better understanding of the functioning of these rural livelihoods and identify key socio-economic and environmental drivers affecting food insecurity.

Participatory on-farm trials (being led by KARI): A set of agricultural technologies consisting of high-value traditional crops and integrated soil fertility-water-livestock-pest management practices will be identified, implemented, adapted and evaluated by and with smallholder farmers using an adaptation of the Mother-Baby trial design. Primary Participatory Agricultural Technology Evaluation (PPATE; i.e., Mother) on-farm trials will be established in October 2011 in a subset of 18 FRDAs. Set up in farmers' fields but under controlled conditions, these trials will permit rigorous statistical analyses and comparison of different practices. In October 2012, Secondary Participatory Agricultural Technology Evaluation (SPATE; i.e., Baby) trials will be set-up in all FRDAs, and managed by the farmers themselves. Kenyan partners, as mentioned above, will recruit farmer participants and run the on-farm trial in this study. The identification, implementation and evaluation of agricultural technologies will be guided by a PLAR conceptual framework, which is *a learning and innovation platform which brings together farmers, researchers and other stakeholders to jointly analyze farming and natural resource management issues, identify problems, seek and develop solutions to those problems, and implement and evaluate these solutions, in an iterative learning-action cycle*. Stakeholder workshops/learning events will be held at regular intervals to share knowledge about sustainable and equitable food security and environmental management issues, discuss agricultural technological and institutional innovations, and conceive 'road maps' for subsequent project activities. The PLAR process includes a number of Participatory Rural Appraisal (PRA) and training activities to identify and assess agricultural technologies, design a participatory monitoring and evaluation framework (PM&E), assess market constraints and potentials, raise awareness about gender, nutrition and health issues, and strengthen social capital in these rural communities.

Baseline study (being led by KARI): Two key components of the baseline study are focus group discussions and the baseline household survey. Focus groups will be held in each County and used to gather qualitative data while facilitating discussions among farmers. The focus group activities address a range of questions related to issues of gender relations, decision making, and policy and are being implemented by KARI and the MoA. The household survey will be administered jointly by McGill and KARI following the two different sampling strategies described in Section 2 above. The survey will be used to gather information on household characteristics and decision-making processes regarding the management of resources (human, financial, natural), and monitoring and evaluation indicators to measure project impact. The questionnaire has been developed through a series of iterations between researchers from McGill, KARI and KEMRI. A draft copy of the questionnaire is presented in Appendix D. Note that the exact codes for some of the questions are currently being prepared. The questionnaire will take approximately 120 minutes to administer. Enumerators will be identified and receive some training in April 2012. A pre-test of the questionnaire will be performed during the training of the enumerators. Modifications to the questionnaire will then be performed as required. The plan is to administer the questionnaire in May 2012.

Integrated Assessment: The purpose of the integrated assessment undertaken in this project is to provide a holistic, systemic and multiscale understanding of social, economic, environmental, institutional and policy dimensions of sustainable food security, with the potential for new insights into what underlies low adoption and up-scaling of technologies. The integrated assessment component of the research will be articulated around seven research streams under the responsibility of a team of McGill and KARI researchers. Note that other Kenyan research institutions will participate in some of these streams (e.g., KEMRI in Nutrition & Health). Below is an overview of the issues to be addressed by the different research streams. Note that for the purpose of the REB application, research activities associated with these different streams will be presented as separate Appendices.

McGill Research Streams:

I. Institutional Economics: Examining participation dynamics is central to understanding adoption of technological advancements for food security. This research stream uses a multi-dimensional framework to analyze the reasons for adoption of a particular agricultural enhancement. We will conduct surveys among farmers who have adopted resilient farming system practices and among those who reject these practices. By comparing participating and non-participating farmers, we draw lessons for the development of approaches that are adequate to the local culture and agricultural practices. McGill stream leader: Nicolas Kosoy.

A PhD student, Patrick Cortbaoui, has been recruited in January 2012 to work with Dr. Nicolas Kosoy and the Economics research stream. Due to the need to further develop the field research activities in partnership with KARI, the details of this research stream are not yet available for inclusion. All aspects of this research stream that will involve human subjects will be submitted as an amendment to this application for REB approval.

II. Nutrition & Health: Food security encompasses access to sufficient safe and nutritious food to meet dietary needs and food preferences for a healthy and active life. Assessment of nutrition outcomes mediated through increased consumption of food produced on farm and/or from improved household income is key to both evaluating the project impact and for understanding the complex dynamics mediating this impact. Together with Environment & NRM stream, this research stream will also look at linkages between the agro-biodiversity and nutrition. McGill stream leader: Tim Johns.

A PhD student, Megan Dilbone, started in September 2011. She is planning to go to Kenya in April 2011. Her planned research activities for this first trip to Kenya are presented in Appendix C.

III. Gender Mainstreaming and Analysis: Gender equality is a cross-cutting analytical, methodological and practical theme that is closely woven throughout all phases and aspects of the project. One important gendered aspect of the project is the use of animation methodologies and the Triple-A cycle of *analysis-action-assessment*, developed in UNICEF's Child Survival, Protection and Development program and adapted by the

Tanzania Gender Networking Programme for gender analysis. It is taken up here as a key feature of the iterative, participatory research design. As part of the first phase of project activities, a 'gender team' made up of women farmers and researchers from McGill and KARI will carry out a 'gender audit' of activities proposed within each research stream. This 'audit' ensures gendered categories, power relations and disaggregation of data are taken into account by all researchers in particular at the early phase during baseline survey activities. The gender team also ensures balance in the mobilization of farmers through outreach and sensitization. McGill stream leader: Leigh Brownhill.

Due to the need to further develop the field research activities in partnership with KARI, many of the details of this research stream are not yet available for inclusion. Any aspects of this research stream that will involve human subjects will be submitted as amendments to this application for REB approval.

IV. Land tenure: The central question in this stream concerns the effect of land holding on the nature of farming systems, farmers' approach to innovation, and resulting levels of poverty. A survey of rural households will assess the legal form of tenure under which farms are held, the size of holdings, and the nature of resource 'governance'. Assessing the legal status of holdings, the size and degree of fragmentation, and the regime of resource governance, represents the first stage of examining the effects of property on the farming system, on the process of innovation, and on poverty. The second stage will be to assess how variability in farming system characteristics (such as range of crops grown, level of yields, use of livestock, presence of woodlots, household incomes) relates to the nature of land holding.

With respect to innovation, we will examine whether willingness to innovate is an outcome, or a correlate, of holding private land, of holding land on a larger scale, relatively individualized rather than communal strategies of resource governance, and factors of education and income. We examine what forms of land holding and farming are practiced by the relatively richer and poorer farmers, and whether conditions of relative poverty are related to an openness to innovation, strategies of risk minimization, and differential productivity of different farming practices. McGill stream leader: John Galaty.

Due to the need to recruit students and further develop the field research activities in partnership with KARI, the details of this research stream are not yet available for inclusion. All aspects of this research stream that will involve human subjects will be submitted as an amendment to this application for REB approval.

V. Policies & Institutions: This research stream explores how the findings generated through the other research streams can best impact operational food management strategies within a range of institutional and regulatory contexts in Kenya and East Africa. Using a grounded theory research paradigm, this stream involves four inter-related components:

Retrospective research (analysis of processes): This component provides a comparative analysis of how institutional arrangements of government in Kenya influence food security-related outcomes. Will involve interviews, focus groups and document analysis.

Multiple Case Study research (analysis of practice): Multiple case study analysis will be used to conduct an analysis of relationships among farmers, community groups, researchers, industry groups, NGOs and the government agencies responsible for agricultural production within a 'real life' context. Will involve interviews, participant observation, focus groups, participatory mapping, survey and document analysis.

*Delphi (analysis of expert knowledge/experience):*A Concept Mapping Policy Delphi will be used to analyze future opportunities to enhance adoption of resilient farming systems in semi-arid Kenya. 'Experts' include government researchers, academics, senior bureaucrats, community leaders, industry researchers, CBOs and NGOs. Will involve focus groups.

Survey research (analysis of stakeholder perceptions): Survey research will extract information on the perceptions of all stakeholders involved with efforts to enhance food security, livelihoods and environmental sustainability. McGill stream leader: Gordon Hickey.

REB application for Colleen Eidt (PhD) and Stephanie Shumsky (MSc) research activities are presented in Appendices A and B, respectively.

VI. Environment & Natural Resource Management: We will examine decision-making processes taking place at household and community levels in relation to management of ecosystems services and the natural resource base (including soil, water, seeds, biodiversity). This analysis of farming systems should help identify and adapt technologies suited to farmers' needs. Farmers are typically engaged in a number of NRM activities, such as erosion control, water harvest schemes, fodder banks for livestock, and use and maintenance of common property. An ecosystem services perspective highlights the role of common property in maintaining resilience of rural livelihoods and enhancing food security. We will also identify environmental indicators relevant to farm-level decision making. McGill stream leaders: Elena Bennett and Jim Fyles.

Purity Kagure Karuga (PhD) has been recruited for that stream but will only start in May 2012. Any aspect of this research stream that will involve human subjects will be submitted as an amendment to this application for REB approval.

VII. Knowledge integration: This seventh research stream addresses the development of best practices to integrate knowledge generated by research streams, local communities and other stakeholders. Three aspects of knowledge integration will be considered. First, a review of tools and approaches proposed to synthesize knowledge, prioritize problems and identify key processes (i.e., scoping), and develop shared representations of rural livelihood system will be conducted. A suite of methods (e.g., models, concept mapping, various matrices, role plays, scenario analyses) will be tested during workshops and learning events, and best practices identified. Second, the role of facilitation and leadership in enabling successful knowledge integration among stakeholders with multiple perspectives, values and aspirations will be examined. We will assess best practices to ensure participation of, and facilitate communication between, stakeholders, bridge the gaps between disciplines, sectors, cultures, and social strata, and mediate between divergent views and interests. This deliberative and negotiated component of knowledge integration ensures that agricultural innovations are built on knowledge that is reconciliatory. Third, the potential of institutional arrangements (networks, partnerships, boundary spanning organizations) proposed to enable knowledge integration will be assessed. McGill stream leaders: Gordon Hickey and Bernard Pelletier.

Any aspect of this research stream that will involve human subjects will be submitted as an amendment to this application for REB approval.

Note on Research Streams and what is included in this REB application:

Please note that this application addresses activities by McGill researchers that have been identified so far. In addition to the baseline household survey, which cuts across all McGill research teams, each research stream is required to separately fill the eight (8) sections of the REB application and provide their own set of consent forms. Although this will mean that some of the information provided will be redundant, it will also permit each research component to be assessed individually. This application thus includes the baseline survey, and research activities by Colleen Eidt, Stephanie Shumsky, Megan Dilbone. Other project team members will submit separate amendments to this protocol, which address each specific set of data collection activities within their particular research streams, as outlined above.

5. Potential Risks

a) Describe any known or foreseeable risks, if any, that the subjects or others might be subject to during or as a result of the research. Risks may be psychological, physical, emotional, social, legal, economic, or political.

One potential risk is the generation of unrealistic expectations among local communities and agricultural extension workers. In effect, the presence and involvement of the McGill team could give the impression that large amounts of money will now be available to address and solve the various problems faced by these communities.

b) In light of the above assessment of potential risks, indicate whether you view the risks as acceptable given the value or benefits of the research.

This risk is deemed acceptable given the value or benefits of the research. Furthermore, mitigation strategies to address this will be systematically incorporated in the project design (see below).

c) Outline the steps that may be taken to reduce or eliminate these risks. If deception is used, justify the use of the deception and indicate how subjects will be debriefed or justify why they will not be debriefed.

This research will be conducted within a participatory action research framework where smallholder farmers and other stakeholders will not only be clearly informed about the objectives of the project but be directly involved in the overall design of the research. Standard KSARI procedures for remuneration will be followed.

6. Privacy and Confidentiality

Describe the degree to which the anonymity of subjects and the confidentiality of data will be assured and the specific methods to be used for this, both during the research and in the release of findings. This includes the use of data coding systems, how and where data will be stored, who will have access to it, what will happen to the data after the study is finished, and the potential use of the data by others. Indicate if there are any conditions under which privacy or confidentiality cannot be guaranteed (e.g. focus groups), or, if confidentiality is not an issue in this research, explain why.

A number of data collection tools will be used by the McGill team throughout this research project. These include interviews, focus group discussions, survey questionnaires, and participatory rural appraisal activities. For each of these tools, issues of anonymity of subjects and use of the data will be addressed. Detailed procedures associated with the use of these different data collection tools will be presented in more detail in the Appendices corresponding to the research streams except for the baseline household survey, which cuts across the different streams and is presented below:

<u>Handling of data from baseline household survey:</u>

i. The survey questionnaire will be administered only after informed consent of the respondent. The text to be read to the respondent is included at the beginning of the questionnaire (see Appendix D);

ii. The hard-copy (paper) of the questionnaire will include both the respondent identification and a reference number (HH specific code);

iii. When entering the data in the database/spreadsheet, however, we will only input the reference number (household code) of the questionnaire;

iv. A separate file with restricted access will be maintained linking the respondent information and the reference number;

v. Only the database/spreadsheet containing the reference number will be made available to researchers and students from KARI and McGill for analysis. The hard-copy of the questionnaire will have restricted access and thus only a limited number of people will have access to the identifiable data;

vi. In situations where some of the research teams would like to pursue research activities (e.g., in-depth interviews) with specific households that have participated in the survey, the information about specific respondent may be released but only after the team submits a formal request and/or proposal to be approved by the Principal Investigators/Project Managers (we can specify this at a later stage) - this needs to be clarified with the respondents, however - i.e. they should be informed and consent to the possibility that they may be approached again by the research team with the option of opting out at any time. Furthermore, any new research activities to take place with households that previously participated in the survey will require additional and proper informed consent by the participants.

Because of the large number of scientists involved in the project and the numerous research components, the project management team is preparing some general rules and guidelines regarding the use of data and the protection of research subjects.

7. Informed Consent Process

Describe the oral and/or written procedures that will be followed to obtain informed consent from the subject. Attach all consent documents, including information sheets and scripts for oral consents. If written consent will not be obtained, justification must be provided (Examples of written consent forms you will find at the end of this document).

The project will be described in detail to each informant before the interview, survey, focus group or other participatory activity begins. Informants will be invited to ask any questions about the research and the researchers will answer these questions. Then participants will be asked to either sign the research consent form prior to the commencement of interviews or discussions or give their oral consent. Each research stream will developed its own set of informed consent form(s), which are attached in the appendices.

8. Other Concerns

a) Indicate if the subjects are a captive population (e.g. prisoners, residents in a center) or are in any kind of conflict of interest relationship with the researcher such as being students, clients, patients or family members. If so, explain how you will ensure that the subjects do not feel pressure to participate or perceive that they may be penalized for choosing not to participate.

Not applicable

b) Comment on any other potential ethical concerns that may arise during the course of the research.

There are no other concerns at this time.

MCGILL UNIVERSITY
RESEARCH ETHICS BOARD-
FACULTY OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

8.2 **Appendix 2** – Ethics Review Amendment Request where relevant to the economic streams of Enhancing Ecologically Resilient Food Security through Innovative Farming Systems in the Semi-Arid Midlands of Kenya

MCGILL UNIVERSITY
FACULTY OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

ETHICS REVIEW
AMENDMENT REQUEST

This form can be used to submit any changes/updates to be made to your currently approved research project. Explain what these changes are, and attach any relevant documentation that has been revised. Significant changes that have ethical implications must be reviewed and approved by the REB before they can be implemented.

REB File #: 969-0511

Project Title: Enhancing Ecologically Resilient Food Security through Innovative Farming Systems in the Semi-Arid Midlands of Kenya

Principal Investigator: Dr. Gordon Hickey

Department/Phone/Email: (514) 398-7214; gordon.hickey@mcgill.ca

Faculty Supervisor (for student PI):

Amendment Description:

(1) Additions were made to research activities to be undertaken by Stephanie Shumsky (M.Sc.) – see Appendix 1.
(2) New research activities to be undertaken by Patrick Cortbaoui (PhD), Dr. Nicolas Kosoy (Assistant Professor) and Prof. John Galaty have been added – see Appendix 2.

Principal Investigator Signature: [signature] Date: 5/6/2012

Faculty Supervisor Signature: ______________ Date: ________
(for student PI)

For Administrative Use	**REB:** _x_ AGR ___ EDU ___ REB-I ___ REB-II

_x_ Expedited Review ___ Full Review

_x_ This amendment request has been approved.

Signature of REB Chair/ designate: [signature]
Elias Georges, Interim Chair

Date: June 07, 2012

Submit signed original to the Macdonald Research Office, Raymond Building, Room R3-032a; Fax: 398-8732 or lynn.murphy@mcgill.ca. Electronic submissions with scanned signatures are accepted but must come from the PI's McGill email.

(August 2011)

APPENDIX 2 – Research Activities by Patrick Cortbaoui – Institutional Economics Research Stream

STUDENT: Patrick Cortbaoui (PhD), Department of Natural Resource Sciences

TITLE: *Building an agricultural commodity to satisfy food security needs: A novel framework to integrate ecological economics to food security strategies.*

SUPERVISOR: Nicolas Kosoy (Department of Natural Resource Sciences)

CO-INVESTIGATORS: John Galaty & Stephen Moiko (Department of Anthropology) – Land Tenure Research Stream

1. Purpose of the Research

Describe the proposed project and its objectives, including the research questions to be investigated (one page maximum). What is the expected value or benefits of the research? How do you anticipate disseminating the results (e.g. thesis, presentations, internet, film, publications)?

The general objective of this research component is to assess opportunity costs in relationship to land tenure regimes in the field focusing at the household level in three semi-arid counties of Kenya (Machakos, Makueni and Tharaka). We will also look at how land tenure affect decision-making with regard to crop choice, subsistence, marketing and internal allocation within local groups, paying particular attention to gender, generations and ethnic dimensions.

2. Recruitment of Subjects/Location of Research

Describe the subject population and how and from where they will be recruited. If applicable, attach a copy of any advertisement, letter, flier, brochure or oral script used to solicit potential subjects (including information sent to third parties). Describe the setting in which the research will take place. Describe any compensation subjects may receive for participating.

This research component will be located in Machakos, Tharaka and Makueny Counties and scheduled from 11 June until 18 July 2012 in order to collect data on local crops, associated costs and benefits that will help us derive local opportunity costs for different land uses. Household members targeted for surveys and interviews will be selected with the assistance of partners from McGill and the Kenya Agricultural Research Institute (KARI). The recruitment process will follow the guidelines recommended by KARI professionals who already have significant experience doing this task. People will be randomly chosen from the communities within the three Counties to estimate the opportunity costs and try to determine the obstacles that constraint them from adopting those crops. At the same time, interviewing people from formal and informal institutions into the Machakos area will follow these surveys. Monetary compensation to participants will not be given, however, some sort of food and beverage will be provided to show respect and gratitude. Decisions regarding any compensation will be done in consultation with the KARI partners.

3. Other Approvals

When doing research with various distinct groups of subjects (e.g. school children, cultural groups, institutionalized people), organizational/community/governmental permission is sometimes needed. If applicable, how will this be obtained? Include copies of any documentation to be sent.

Submit signed original to the Macdonald Research Office, Raymond Building, Room R3-032a; Fax: 398-8732 or lynn.murphy@mcgill.ca. Electronic submissions with scanned signatures are accepted but must come from the PI's McGill email.

(August 2011)

KARI is a parastatal organization and therefore does not require additional governmental permission to conduct research within Kenya. Since the proposed research is part of the KARI – McGill joint partnership, no additional government permission is required. At the community level there are protocols for conducting research, for example first speaking with the local agricultural officer and chief. KARI is very familiar with these protocols and will provide the necessary guidelines and contacts to ensure that the appropriate procedures are followed.

4. Methodology/Procedures

Provide a sequential description of the methods and procedures to be followed to obtain data. Describe all methods that will be used (e.g. fieldwork, surveys, interviews, focus groups, standardized testing.

Methods for assessing opportunity costs in relation to land tenure regimes among members of the poor communities who grow orphan crops or used to grow them but replaced them with cash or major crops can be classified into four categories including (1) Baseline surveys (described in REB file 969-0511), (2) Complementary quantitative surveys, (3) Informal interviews, and (4) Secondary information. In addition, methods for assessing the role of formal and informal institutions will be limited to (1) Informal interviews and (2) Secondary information.

5. Potential Risks

a) Describe any known or foreseeable risks, if any, that the subjects or others might be subject to during or as a result of the research. Risks may be psychological, physical, emotional, social, legal, economic, or political.

The potential risk of this study is the generation of unrealistic expectations among local communities and agricultural extension workers. The presence of McGill University researchers could give the impression that large amounts of money will now be available to address and solve the various problems faced by these communities.

b) In light of the above assessment of potential risks, indicate whether you view the risks as acceptable given the value or benefits of the research.

This risk is deemed acceptable given the value and benefits of the research.

c) Outline the steps that may be taken to reduce or eliminate these risks. If deception is used, justify the use of the deception and indicate how subjects will be debriefed or justify why they will not be debriefed.

Mitigation strategies to address this risk will be systematically incorporated in the research design. Prior to participation farmers and other stakeholders who choose to participate in this research will be clearly informed about the objectives and expected results of the study to avoid the generation of unrealistic expectations. Subjects will be invited to ask any questions about the research and these questions will be answered.

6. Privacy and Confidentiality

Describe the degree to which the anonymity of subjects and the confidentiality of data will be assured and the specific methods to be used for this, both during the research and in the release of findings.

This includes the use of data coding systems, how and where data will be stored, who will have access to it, what will happen to the data after the study is finished, and the potential use of the data by others. Indicate if there are any conditions under which privacy or confidentiality cannot be guaranteed (e.g. focus groups), or, if confidentiality is not an issue in this research, explain why.

All participants in this study will remain completely anonymous in the final thesis as well as in any publications, unless written consent to be identified is attained. All data collected will be confidential and as such will be stored under lock and key. During the data collection process all data will be brought back to a secure location where it will be stored in a safe or on a password protected computer. During transportation all data will be stored in a locked, carry-on bag. Upon return to McGill University all data will be stored on a secure, password protected server. Only KARI and McGill researchers involved in the KARI – McGill joint project will have access to data and data analyses, including any coding systems that may be developed over the course of the study. Two years after the completion of this study all data and data analyses will be destroyed.

7. Informed Consent Process

Describe the oral and/or written procedures that will be followed to obtain informed consent from the subject. Attach all consent documents, including information sheets and scripts for oral consents. If written consent will not be obtained, justification must be provided (Examples of written consent forms you will find at the end of this document).

The project will be described in detail to each informant before the interview, survey, focus group or other participatory activity begins. Informants will be invited to ask any questions about the research and the researchers will answer these questions. Then participants will be asked to either sign the research consent form prior to the commencement of interviews or discussions or give their oral consent.

8. Other Concerns

a) Indicate if the subjects are a captive population (e.g. prisoners, residents in a center) or are in any kind of conflict of interest relationship with the researcher such as being students, clients, patients or family members. If so, explain how you will ensure that the subjects do not feel pressure to participate or perceive that they may be penalized for choosing not to participate.

Not applicable.

b) Comment on any other potential ethical concerns that may arise during the course of the research.

No other concern.

Submit signed original to the Macdonald Research Office, Raymond Building, Room R3-032a; Fax: 398-8732 or lynn.murphy@mcgill.ca. Electronic submissions with scanned signatures are accepted but must come from the PI's McGill email.

(August 2011)

APPENDIX 2.1 CONSENT FORM (Patrick Cortbaoui)

Title of Research: Building an agricultural commodity to satisfy food security needs: A novel framework to integrate ecological economics to food security strategies.

Researcher: Patrick Cortbaoui, Ph.D. Candidate, Natural Resource Sciences - Environment
Contact Information: Tel: 514-622-6622; email: patrick.cortbaoui@mail.mcgill.ca
Supervisor: Dr. Nicolas Kosoy; Tel: 514-398-7944
Co-investigators: Prof. John Galaty and Stephen Moiko

Good morning/afternoon. We are coming from the Kenya Agricultural Research Institute with permission from the Government through Ministry of Agriculture. We are conducting a survey looking at obstacles affecting the adoption of orphan crops in the Machakos region of Kenya. We would like to ask you some questions that should take no more than two hours of your time. We would like to share some of this information widely in order that more people understand how food is grown and used in this region and the issues that you face regarding food production and soil, water and land management.

Your signature below serves to signify that you agree to participate in this study.

Your participation is entirely voluntary and you can choose to decline to answer any question or even to withdraw at any point from the project. Anything you say will only be attributed to you with your permission; otherwise the information will be reported in such a way as to make direct association with yourself impossible. My pledge to confidentiality also means that no other person or organization will have access to the interview materials and that they will be coded and stored in such a way as to make it impossible to identify them directly with any individual.

Research Ethics Board Contact Information:
If you have any questions or concerns about your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer at 514-398-6831.

Consent: I wish to be identified in the report ____YES _____NO
I have read the above information and I agree to participate in this study
Signature: __________________
Name: ______________________

Submit signed original to the Macdonald Research Office, Raymond Building, Room R3-032a; Fax: 398-8732 or lynn.murphy@mcgill.ca. Electronic submissions with scanned signatures are accepted but must come from the PI's McGill email.

(August 2011)

APPENDIX 2.2 Complementary Quantitative survey – Patrick Cortbaoui

Sketch of the shamba

What do you normally grow on your land? Please specify human and animal edible varieties
How many times a year does XXX produce? Determine the number of seasons

Crop	Area under cultivation	Season	Season

Assume I have land of 1 acre in this County and I want to start growing _______, what is the first thing I have to do (clearing the land, preparing the land….)?
After I completed ________, what should I do? Continue just before XX enters the market or is consumed
Should I use fertilizers? How is it called? How much should I use?
Is there any natural fertilizer I can use? How much should I use?
Should I use pesticides? How is it called? How much should I use?
Is there any natural pesticide I can use? How much should I use?
How much ______ can I expect from my land? In a good season? In a bad season?

Crop ________:

Submit signed original to the Macdonald Research Office, Raymond Building, Room R3-032a; Fax: 398-8732 or lynn.murphy@mcgill.ca. Electronic submissions with scanned signatures are accepted but must come from the PI's McGill email.

(August 2011)

__________Kg produced (Good Season)
___________Kg produced (Good Season)

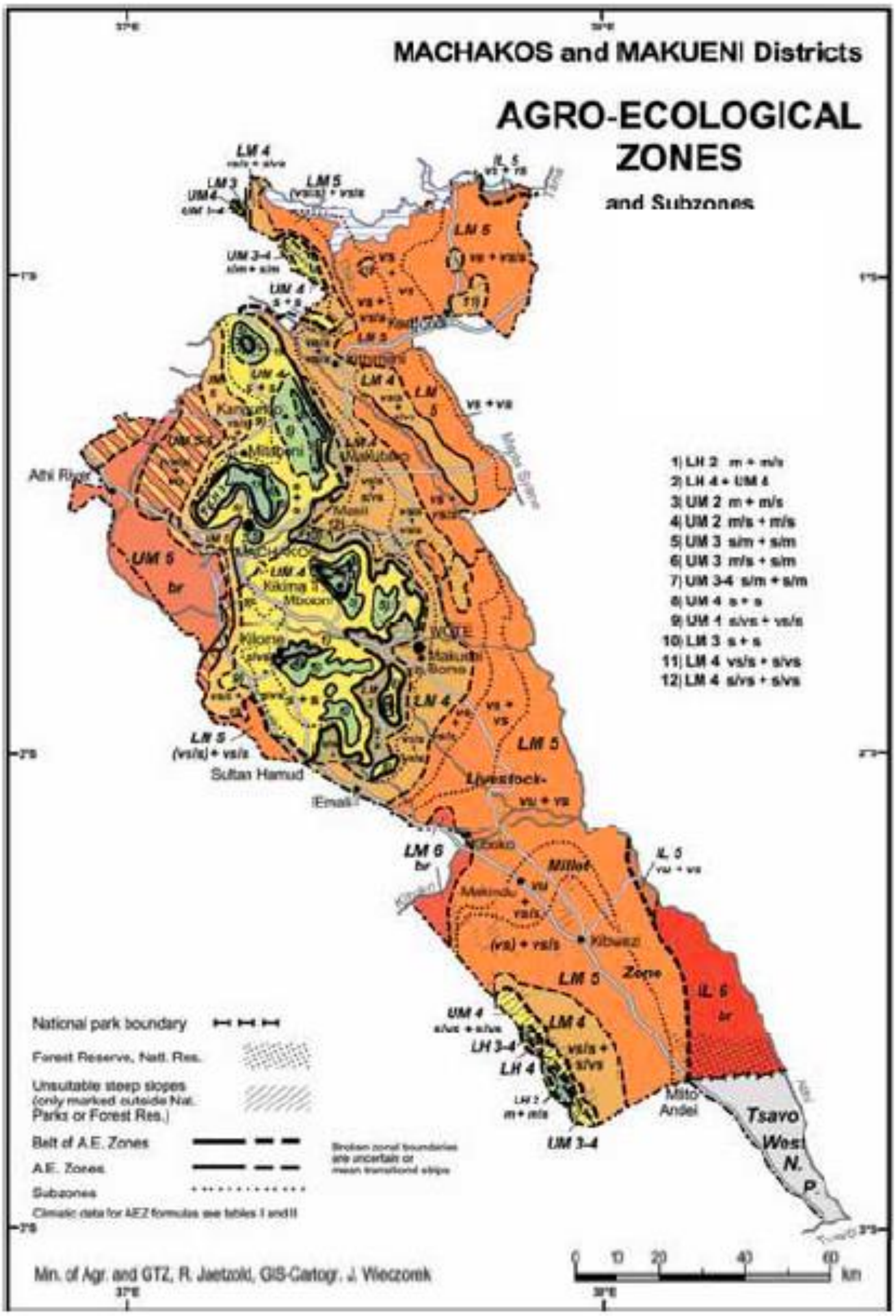
Activities	Duration	Season

Comments:

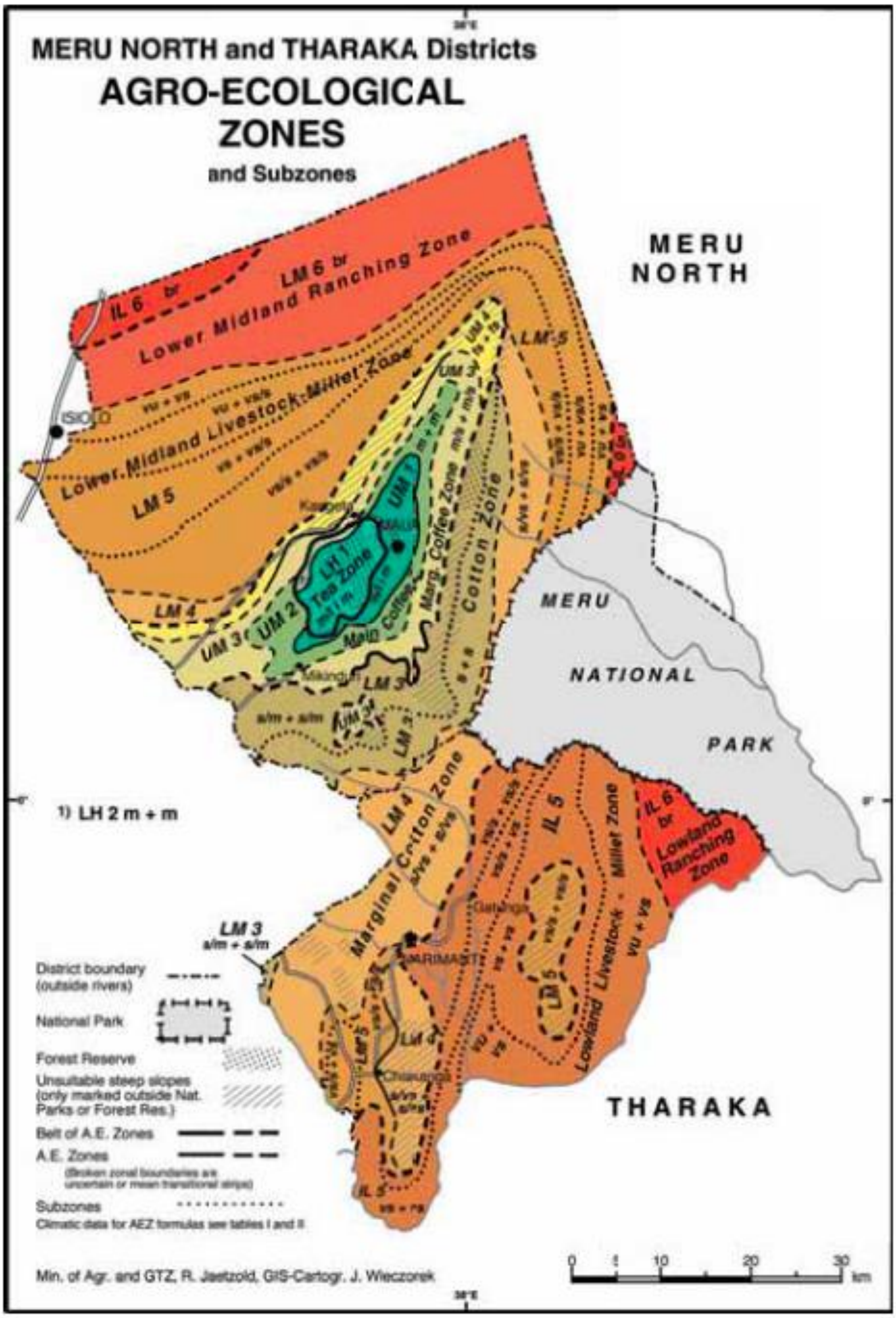
Submit signed original to the Macdonald Research Office, Raymond Building, Room R3-032a; Fax: 398-8732 or lynn.murphy@mcgill.ca. Electronic submissions with scanned signatures are accepted but must come from the PI's McGill email.

(August 2011)

8.3 **Appendix 3 –** Agro-Ecological Zone map of Machakos & Makueni Counties (Ralph et al., 2006)



8.4 Appendix 4 – Agro-Ecological Zone map of Tharka-Nithi and Meru North Counties (Ralph et al., 2006)



8.5 Appendix 5 – Survey

KARI-McGill Food Security Project – Economic Stream
Complementary Quantitative Survey Questionnaire

SKETCH OF THE SHAMBA

INTRODUCTION AND CONSENT BY MAIN RESPONDENT

Before the beginning of the interview read out the following paragraph and ensure that the respondent understands before asking for consent.

"Good morning/afternoon. We are coming from the Kenya Agricultural Research Institute with permission from the Government through Ministry of Agriculture. We are conducting a survey ***looking at obstacles affecting the adoption of orphan crops in the Machakos region of Kenya.*** *We would like to ask you some questions that should take no more than* ***one hour*** *of your time. We would like to share some of this information widely in order that more people understand how food is grown and used in this region and the issues that you face regarding food production and soil, water and land management.*
Your signature below serves to signify that you agree to participate in this study.

Your participation is entirely voluntary and you can choose to decline to answer any question or even to withdraw at any point from the project. Anything you say will only be attributed to you with your permission; otherwise the information will be reported in such a way as to make direct association with yourself impossible. My pledge to confidentiality also means that no other person *or organization will have access to the interview materials and that they will be coded and stored in such a way as to make it impossible to identify them directly with any individual.*

If you have any questions or concerns about your rights or welfare as a participant in this research study, please contact: ***Esther Njuguna, Research Associate, KARI-HQ, Nairobi; +254 725 896 158***

Consent: I wish to be identified in the report ____YES ____NO

I have read the above information and I agree to participate in this study

Signature: ______________

Name: _________________

SECTION 00: AGRONOMICAL INFORMATION

1.1 What do you normally grow on your land? Please specify human and animal edible varieties.

1.2 How many times a year does each crop produce? Please determine the number of seasons.

Crop	Human or animal consumption	Area under cultivation (acres)	Season

CROP:____________________
SECTION 01: AGRONOMICAL PRACTICES

Assume I have land of ________(acres) in this County and I want to start growing __________

2.1 What is the first thing I have to do (clearing the land, preparing the land….)?

____
____
____

2.2 What should I do next? (Continue just before _________ enters the market or is consumed)

Activities	Duration	Season

2.3 Should I use fertilizers? How is it called? How much should I use?

____
____

2.4 Is there any natural fertilizer I can use? How much should I use?

____
____

2.5 Should I use pesticides? How is it called? How much should I use?

____

____

2.6 Is there any natural pesticide I can use? How much should I use?

____

____

2.7 How much ________ can I expect from my land? In a good season? In a bad season?

____________Kg produced (Good Season)

____________Kg produced (Bad Season)

SECTION 02: COST OF PRODUCTION

In this section, we are trying to collect data about the cost of producing ________per season.

Parameter	Description	Price
Cultivated land	Owner	
	Tenant	
Seeds	Imported Improved	
	Imported Not Improved	
	Local Improved	
	Local Not Improved	
Pesticides	Natural	
	Synthetic	
Fertilizers	Natural	
	Synthetic	
Water supply	Treated	
	Not Treated	
Labor cost	Household Member	
	Household Not Member	
Technology	Pre-Harvest	
	Post-Harvest	
Access to market	With Transportation	
	Without Transportation	

Comments:

____

____

___

____

____

___

____

____

___

CROP:____________________

SECTION 01: AGRONOMICAL PRACTICES

Assume I have land of ________(acres) in this County and I want to start growing __________

2.1 What is the first thing I have to do (clearing the land, preparing the land….)?

____

____

____

2.2 What should I do next? (Continue just before _________ enters the market or is consumed)

Activities	Duration	Season

2.3 Should I use fertilizers? How is it called? How much should I use?

____

____

2.4 Is there any natural fertilizer I can use? How much should I use?

____

____

2.5 Should I use pesticides? How is it called? How much should I use?

____

____

2.6 Is there any natural pesticide I can use? How much should I use?

____

____

2.7 How much ________ can I expect from my land? In a good season? In a bad season?

____________Kg produced (Good Season)

____________Kg produced (Bad Season)

SECTION 02: COST OF PRODUCTION

In this section, we are trying to collect data about the cost of producing ________per season.

Parameter	Description	Price
Cultivated land	Owner	
	Tenant	
Seeds	Imported Improved	
	Imported Not Improved	
	Local Improved	
	Local Not Improved	
Pesticides	Natural	
	Synthetic	
Fertilizers	Natural	
	Synthetic	
Water supply	Treated	
	Not Treated	
Labor cost	Household Member	
	Household Not Member	
Technology	Pre-Harvest	
	Post-Harvest	
Access to market	With Transportation	
	Without Transportation	

Comments:

____

____

___

____

____

___

____

____

___

CROP:__________________

SECTION 01: AGRONOMICAL PRACTICES

Assume I have land of ________(acres) in this County and I want to start growing __________

2.1 What is the first thing I have to do (clearing the land, preparing the land….)?

____

____

____

2.2 What should I do next? (Continue just before _________ enters the market or is consumed)

Activities	Duration	Season

2.3 Should I use fertilizers? How is it called? How much should I use?

____

____

2.4 Is there any natural fertilizer I can use? How much should I use?

____

____

2.5 Should I use pesticides? How is it called? How much should I use?

____

____

2.6 Is there any natural pesticide I can use? How much should I use?

____

____

2.7 How much ________ can I expect from my land? In a good season? In a bad season?

____________Kg produced (Good Season)

____________Kg produced (Bad Season)

SECTION 02: COST OF PRODUCTION

In this section, we are trying to collect data about the cost of producing ________per season.

Parameter	Description	Price
Cultivated land	Owner	
	Tenant	
Seeds	Imported Improved	
	Imported Not Improved	
	Local Improved	
	Local Not Improved	
Pesticides	Natural	
	Synthetic	
Fertilizers	Natural	
	Synthetic	
Water supply	Treated	
	Not Treated	
Labor cost	Household Member	
	Household Not Member	
Technology	Pre-Harvest	
	Post-Harvest	
Access to market	With Transportation	
	Without Transportation	

Comments:

____

____

____

____

____

____

CROP:________________

SECTION 01: AGRONOMICAL PRACTICES

Assume I have land of ________(acres) in this County and I want to start growing __________

2.1 What is the first thing I have to do (clearing the land, preparing the land....)?

____

____

____

2.2 What should I do next? (Continue just before _________ enters the market or is consumed)

Activities	Duration	Season

2.3 Should I use fertilizers? How is it called? How much should I use?

____

____

2.4 Is there any natural fertilizer I can use? How much should I use?

____

____

2.5 Should I use pesticides? How is it called? How much should I use?

____

____

2.6 Is there any natural pesticide I can use? How much should I use?

____

____

2.7 How much ________ can I expect from my land? In a good season? In a bad season?

___________Kg produced (Good Season)

___________Kg produced (Bad Season)

SECTION 02: COST OF PRODUCTION

In this section, we are trying to collect data about the cost of producing ________per season.

Parameter	Description	Price
Cultivated land	Owner	
	Tenant	
Seeds	Imported Improved	
	Imported Not Improved	
	Local Improved	
	Local Not Improved	
Pesticides	Natural	
	Synthetic	
Fertilizers	Natural	
	Synthetic	
Water supply	Treated	
	Not Treated	
Labor cost	Household Member	
	Household Not Member	
Technology	Pre-Harvest	
	Post-Harvest	
Access to market	With Transportation	
	Without Transportation	

Comments:

____

____

___

____

____

___

____THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY

9 Bibliography

Agarwala, M., Kumar, S., Treves, A., Naughton-Treves, L., 2010. Paying for wolves in Solapur, India and Wisconsin, USA: Comparing compensation rules and practice to understand the goals and politics of wolf conservation. Biol. Conserv. 143, 2945–2955. doi:10.1016/j.biocon.2010.05.003

AGRA, 2014. Africa Agriculture Status Report 2014: Climate Change and Smallholder Agriculture in Sub-Saharan Africa. Alliance for a Green Revolution in Africa (AGRA).

Aiyer, A.K.Y.N., 1950. Mixed cropping in India. Indian J. Agric. Sci. 19, 439–543.

Alila, P.O., Atieno, R., 2006. Agricultural policy in Kenya: Issues and processes, in: A Paper for the Future Agricultures Consortium Workshop, Institute of Development Studies. Institute for Development Studies, pp. 20–22.

Allen, P., 2012. Food Innovation Summit 2012 [WWW Document]. URL http://ezines.tifn.nl/intouch/july2012/06-peter-allen.html

Anderson, E., Martin, J.H., 1949. World production and consumption of millet and sorghum. Econ. Bot. 3, 265–288. doi:10.1007/BF02859097

Ariely, D., 2010. Predictably irrational: the hidden forces that shape our decisions. Harper Perennial, New York.

Bass, L.E., 2004. Child labor in sub-Saharan Africa. Lynne Rienner Publishers, Boulder.

Baumol, W.J., Oates, W.E., 1988. The theory of environmental policy. Cambridge University Press, Cambridge [Cambridgeshire]; New York.

Blowfield, M.E., Dolan, C., 2010. Fairtrade Facts and Fancies: What Kenyan Fairtrade Tea Tells us About Business' Role as Development Agent. J. Bus. Ethics 93, 143–162. doi:10.1007/s10551-010-0558-2

Brondizio, E.S., Ostrom, E., Young, O.R., 2009. Connectivity and the Governance of Multilevel Social-Ecological Systems: The Role of Social Capital. Annu. Rev. Environ. Resour. 34, 253–278. doi:http://dx.doi.org/10.1146/annurev.environ.020708.100707

Bruns, H., 1960. The Economic Importance of Birds in Forests. Bird Study 7, 193–208. doi:10.1080/00063656009475972

Bukania, Z.N., Mwangi, M., Karanja, R.M., Mutisya, R., Kombe, Y., Kaduka, L.U., Johns, T., 2014. Food Insecurity and Not Dietary Diversity Is a Predictor of Nutrition Status in Children within Semiarid Agro-Ecological Zones in Eastern Kenya. J. Nutr. Metab. 2014, 1–9. doi:10.1155/2014/907153

Bulte, E.H., Rondeau, D., 2005. Why Compensating Wildlife for Damages may be Bad for Conservation. J. Wildl. Manag. 69, 14–19. doi:10.2193/0022-541X(2005)069<0014:WCWDMB>2.0.CO;2

Bulte, E., Rondeau, D., 2007. Compensation for wildlife damages: Habitat conversion, species preservation and local welfare. J. Environ. Econ. Manag. 54, 311–322. doi:10.1016/j.jeem.2007.02.003

Byerlee, D., Ali, M., 1999. Productivity Growth and Resource Degradation in Pakistan's Punjab: A Decomposition Analysis, Policy Research Working Papers. The World Bank.

Chambers, R., 1995. Poverty and livelihoods: whose reality counts? Environ. Urban. 7, 173–204. doi:10.1177/095624789500700106

Chambers, R.G., Karagiannis, G., Tzouvelekas, V., 2010. Another Look at Pesticide Productivity and Pest Damage. Am. J. Agric. Econ. 92, 1401–1419. doi:10.1093/ajae/aaq066

Coase, R.H., 1960. The Problem of Social Cost. J. Law Econ. 3, 1–44.

Collinson, M.P., 1983. Farm Management in Peasant Agriculture: Handbook for Rural Development Planning in Africa, 2nd Revised edition edition. ed. Westview Press, Boulder, Colo.

DaCamara-Smeets, M., Manikoski, S., 1975. Research into the control of grain-eating birds (Quelea quelea), phase II. Bird damage and cereal crops in Chad (Field Document No. 41923). FAO, Rome, Italy.

De Mey, Y., Demont, M., Diagne, M., 2012. Estimating Bird Damage to Rice in Africa: Evidence from the Senegal River Valley. J. Agric. Econ. 63, 175–200. doi:10.1111/j.1477-9552.2011.00323.x

Diagne, M., Demont, M., Seck, P.A., Diaw, A., 2013. Self-sufficiency policy and irrigated rice productivity in the Senegal River Valley. Food Secur. 5, 55–68. doi:10.1007/s12571-012-0229-5

Dinar, A., Evenson, R.E., Mendelsohn, R., 1998. Measuring the Impact of Climate Change on Indian Agriculture. World Bank Publications, Washington, D.C.

Ejiogu, A.O., Okoli, V.B., 2012. Bird Scaring Technologies in Rice Production: The need for Policies Prohibiting Participation of Women and Children.

Elliott, C.C.H., 1979. The Harvest Time Method as a Means of Avoiding Quelea Damage to Irrigated Rice in Chad/Cameroun. J. Appl. Ecol. 16, 23–35. doi:10.2307/2402725

Elske, V. de F., Russ, D., John, P., 2002. Farmer researcher teams, farmer field schools and community IPM - Different platforms for different research and learning objectives, in: Wheelbarrows Full of Frogs: Social Learning in Rural Resource Management : International Research and Reflections. p. 09.

Esipisu, I., 2013. Climate-smart Kenyan Crop Hits a Setback – Hungry Birds [WWW Document]. Int. Dev. Res. Cent. IDRC. URL http://www.idrc.ca/EN/Resources/Publications/Pages/ArticleDetails.aspx?PublicationID=1221 (accessed 5.28.14).

FAO, 2014. FAOSTAT [WWW Document]. FAO Stat - Stat. Div. FAO. URL http://faostat3.fao.org/

FAO, 2013a. Climate-Smart Agriculture Sourcebook. Rome.

FAO, 2013b. Climate-smart farming takes root in Kenya [WWW Document]. URL http://www.fao.org/news/story/en/item/178889/icode/ (accessed 8.7.14).

FAO, 2011. Save and grow: a policymaker's guide to sustainable intensification of smallholder crop production. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2005. Production and processing of small seeds for birds (Agricultural and Food Engineering Technical Report). FAO, Rome.

FAO, 2003. Trade Reforms and Food Security: Conceptualizing the Linkages. Commodity Policy and Projections Service, Commodities and Trade Division, Food and Agriculture Organization of the United Nations, Rome.

FAO, 2002. From Farmer Field School to Community IPM: Ten Years of IPM Training in Asia. FAO Community IPM Programme, Food and Agricuture Organization of the United Nations, Regional Office for Asia and the Pacific.

FAO, 1991. Water Harvesting - A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. Rome.

FAO, n.d. Agro-ecological Zoning [WWW Document]. URL http://www.fao.org/docrep/w2962e/w2962e-03.htm (accessed 5.28.14a).

FAO, n.d. FAOSTAT [WWW Document]. FAO Stat - Stat. Div. FAO. URL http://faostat.fao.org/site/375/default.aspx (accessed 8.7.14b).

FAO, IFAD and WFP, 2014. The State of Food Insecurity in the World. Strengthening the enabling environment for food security and nutrition. FAO.

FAO & WFP, 2009. FAO/WFP Crop, Livestock and Food Security Assessment Mission to Namibia.

Fordham, R., 1983. Intercropping - What are the advantages? Outlook Agric. 12, 142–146.

Franklin, B., Epes, S., Wright, H., 1853. The Select Works of Benjamin Franklin: Including His Autobiography. Statesmen.

Gallup, J., Radelet, S., Warner, A., 1998. Economic Growth and the Income of the Poor. Harvard Institute for International Development.

Goetz, A.M., O'Brien, D., 1995. Governing for the Common Wealth? the world Bank's Approach to Poverty and Governance. IDS Bull. 26, 17–26. doi:10.1111/j.1759-5436.1995.mp26002003.x

Government of the Republic of Kenya, 2014. The Kenya Microinsurance Policy Paper. Insurance Regulatory Authority.

Government of the Republic of Kenya, 2013. Second Medium Term Plan, 2013-2017 - Transforming Kenya: A Pathway to Devolution, Socio-Economic Development, Equity and National Unity, Kenya Vision 2030. Ministry of Devolution and Planning, Nairobi.

Government of the Republic of Kenya, 2010. Agricultural Sector Development Strategy (2010-2020). Republic of Kenya.

Gregory, P.J., Ingram, J.S.I., Brklacich, M., 2005. Climate change and food security. Philos. Trans. R. Soc. B Biol. Sci. 360, 2139–2148. doi:10.1098/rstb.2005.1745

Grisley, W., 1997. Crop-pest yield loss: A diagnostic study in the Kenya highlands*. Int. J. Pest Manag. 43, 137–142. doi:10.1080/096708797228834

Gsottbauer, E., van den Bergh, J.C.J.M., 2011. Environmental Policy Theory Given Bounded Rationality and Other-regarding Preferences. Environ. Resour. Econ. 49, 263–304. doi:10.1007/s10640-010-9433-y

Gubbi, S., 2012. Patterns and correlates of human–elephant conflict around a south Indian reserve. Biol. Conserv. 148, 88–95. doi:10.1016/j.biocon.2012.01.046

Hansen, J.W., 2002. Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agric. Syst. 74, 309–330. doi:http://dx.doi.org/10.1016/S0308-521X(02)00043-4

Hardin, G., 1968. The Tragedy of the Commons. Science 162, 1243–1248. doi:10.1126/science.162.3859.1243

Hassan, R., Karanja, D., 1997. Increasing maize production in Kenya: technology, institutions and policy, in: Africa's Emerging Maize Revolution. Lynne Rienner Publishers.

Hedges, S., Gunaryadi, D., 2010. Reducing human–elephant conflict: do chillies help deter elephants from entering crop fields? Oryx 44, 139. doi:10.1017/S0030605309990093

Hill, C.M., 1997. Crop-raiding by wild vertebrates: The farmer's perspective in an agricultural community in western Uganda. Int. J. Pest Manag. 43, 77–84. doi:10.1080/096708797229022

Hollos, M., 2002. The Cultural Construction of Childhood: Changing Conceptions Among the Pare of Northern Tanzania. Childhood 9, 167–189. doi:10.1177/0907568202009002802

Howden, S.M., Soussana, J.-F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H., 2007. Adapting agriculture to climate change. Proc. Natl. Acad. Sci. 104, 19691–19696. doi:10.1073/pnas.0701890104

Hudson, N., 1987. Soil and Water Conservation in Semi-arid Areas. Food & Agriculture Org.

Hurlbert, S.H., 1984. Pseudoreplication and the Design of Ecological Field Experiments. Ecol. Monogr. 54, 187. doi:http://dx.doi.org/10.2307/1942661

IDRC, n.d. Scaling up Agricultural Innovations in Kenya [WWW Document]. IDRC CRDI. URL http://www.idrc.ca/EN/Programs/Agriculture_and_the_Environment/Canadian_International_Food_Security_Research_Fund/Pages/106510.aspx (accessed 8.7.14).

IFAD & CGAP, 2006. Emerging lessons in agricultural microfinance - selected case studies.

IFAD & UNEP, 2013. Smallholders, Food Security and the Environment.

IFPRI, I.F.P., 2014. Global Food Policy Report. International Food Policy Research Institute (IFPRI), Washington, DC.

IPCC, 2007. Africa, in: Climate Change 2007: Impacts, Adaptation and Vulnerability : Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 433–467.

Jensen, M.E., Bourgeron, P.S., 2001. A guidebook for integrated ecological assessments. Springer, New York.

Jodha, N.S., 1980. Intercropping in traditional farming systems. J. Dev. Stud. 16, 427–442. doi:http://dx.doi.org/10.1080/00220388008421770

Jones, P., Thornton, P., 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. Glob. Environ. Change 13, 51–59. doi:10.1016/S0959-3780(02)00090-0

Kabubo-Mariara, J., Karanja, F.K., 2007. The economic impact of climate change on Kenyan crop agriculture: A Ricardian approach. Glob. Planet. Change 57, 319–330. doi:http://dx.doi.org/10.1016/j.gloplacha.2007.01.002

Kapp, K.W., 1969. ON THE NATURE AND SIGNIFICANCE OF SOCIAL COSTS. Kyklos 22, 334–347. doi:10.1111/j.1467-6435.1969.tb02538.x

Kapp, K.W., 1963. The social costs of business enterprise. Spokesman.

KARI, n.d. Machakos County [WWW Document]. KARI-McGill Food Secur. Proj. URL http://www.kari.org/karimcgill/machakos-county (accessed 8.7.14a).

KARI, n.d. Makueni County [WWW Document]. KARI-McGill Food Secur. Proj. URL http://www.kari.org/karimcgill/makueni-county (accessed 8.7.14b).

KARI, n.d. Tharaka County [WWW Document]. KARI-McGill Food Secur. Proj. URL http://www.kari.org/karimcgill/tharaka-county (accessed 8.7.14c).

Katz, C., 1991. Sow What You Know: The Struggle for Social Reproduction in Rural Sudan. Ann. Assoc. Am. Geogr. 81, 488–514. doi:10.1111/j.1467-8306.1991.tb01706.x

Katz, C., 1986. CHILDREN AND THE ENVIRONMENT: WORK, PLAY AND LEARNING IN RURAL SUDAN. Child. Environ. Q. 3, 43–51.

Kfir, R., 2002. Increase in cereal stem borer populations through partial elimination of natural enemies. Entomol. Exp. Appl. 104, 299–306. doi:10.1046/j.1570-7458.2002.01016.x

Kronenberg, J., 2014. What can the current debate on ecosystem services learn from the past? Lessons from economic ornithology. Geoforum 55, 164–177. doi:10.1016/j.geoforum.2014.06.011

Kurukulasuriya, P., Mendelsohn, R., 2008. How Will Climate Change Shift Agro-Ecological Zones And Impact African Agriculture?, Policy Research Working Papers. The World Bank.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M., Eid, H.M., Fosu, K.Y., Gbetibouo, G., Jain, S., Mahamadou, A., Mano, R., Kabubo-Mariara, J., El-Marsafawy, S., Molua, E., Ouda, S., Ouedraogo, M., Séne, I., Maddison, D., Seo, S.N., Dinar, A., 2006. Will African Agriculture Survive Climate Change? World Bank Econ. Rev. 20, 367–388. doi:http://dx.doi.org/10.1093/wber/lhl004

Laukkonen, J., Blanco, P.K., Lenhart, J., Keiner, M., Cavric, B., Kinuthia-Njenga, C., 2009. Combining climate change adaptation and mitigation measures at the local level. Habitat Int. 33, 287–292. doi:10.1016/j.habitatint.2008.10.003

Leblois, A., Quirion, P., 2013. Agricultural insurances based on meteorological indices: realizations, methods and research challenges: Agricultural insurances based on meteorological indices: a survey. Meteorol. Appl. 20, 1–9. doi:http://dx.doi.org/10.1002/met.303

Lee, K.N., 2003. The Drama of the Commons (review). Glob. Environ. Polit. 3, 148–150.

Lenné, J., 2000. Pests and poverty: the continuing need for crop protection research. Outlook Agric. 29, 235–250. doi:10.5367/000000000101293301

Maina, I., Newsham, A., Okoti, M., 2013. Agriculture and Climate Change in Kenya: Climate Chaos, Policy Dilemmas. Future Agricultures.

Mallamaire, L., 1961. La lutte contre les oiseaux granivores en Afrique Occidentale (Mauritanie, Sénégal, Soudan, Niger). J. Agric. Trop. Bot. Appliquée 8, 141–179. doi:10.3406/jatba.1961.6911

Manikowski, S., 1988. Aerial spraying of quelea. Trop. Pest Manag. 34, 133–140. doi:10.1080/09670878809371227

Manikowski, S., 1984. Birds Injurious to Crops in West Africa. Trop. Pest Manag. 30, 379–387. doi:10.1080/09670878409370914

Mankiw, N.G., 2014. Principles of economics.

Martinez-Alier, J., 2002. The environmentalism of the poor: a study of ecological conflicts and valuation. Edward Elgar Pub., Northhampton, MA.

Mathur, P.N., 1963. Cropping pattern and employment in Vidarbha. Indian J. Agric. Econ. 18.

Matson, P.A., 1997. Agricultural Intensification and Ecosystem Properties. Science 277, 504–509. doi:10.1126/science.277.5325.504

May, R.M., 1988. How Many Species are There on Earth? Science, New Series 241, 1441–1449.

Mbata, J., 2013. Agribusiness Indicators: Kenya (No. 82517). The World Bank, Washington, D.C.

McGauley, E., 2004. Bids on the Farm: A Stewardship Guide. Ontario Nature - Federation of Ontario Naturalists, Toronto, Canada.

Mellor, J., 1999. Pro-Poor Growth - The Relation Between Growth in Agriculture and Poverty Reduction. Paper Prepared for USAID/G/EGAD.

Mendelsohn, R. (Ed.), 2001. Global Warming and the American Economy: A Regional Analysis. Edward Elgar Publishing, UK.

Mendelsohn, R., Dinar, A., 2003. Climate, Water, and Agriculture. Land Econ. 79, 328–341. doi:http://dx.doi.org/10.2307/3147020

Mendelsohn, R., Dinar, A., 1999. Climate Change, Agriculture, and Developing Countries: Does Adaptation Matter? World Bank Res. Obs. 14, 277–293. doi:10.1093/wbro/14.2.277

Mendelsohn, R., Dinar, A., Sanghi, A., 2001. The effect of development on the climate sensitivity of agriculture. Environ. Dev. Econ. 6, 85–101.

Mendelsohn, R., Nordhaus, W.D., Shaw, D., 1994. The Impact of Global Warming on Agriculture: A Ricardian Analysis. Am. Econ. Rev. 84, 753–771. doi:http://dx.doi.org/10.1257/aer.89.4.1053

Mendelsohn, R., Nordhaus, W., Shaw, D., 2004. The impact of climate variation on US agriculture, in: The Impact of Climate Change on the United States Economy. Cambridge University Press, Cambridge, UK; New York.

Midega, C.A.O., Salifu, D., Bruce, T.J., Pittchar, J., Pickett, J.A., Khan, Z.R., 2014. Cumulative effects and economic benefits of intercropping maize with food legumes on Striga hermonthica infestation. Field Crops Res. 155, 144–152. doi:10.1016/j.fcr.2013.09.012

Miracle, M.P., 1965. The Introduction and Spread of Maize in Africa. J. Afr. Hist. 6, 39–55. doi:http://dx.doi.org/10.1017/S0021853700005326

Misselhorn, A., Aggarwal, P., Ericksen, P., Gregory, P., Horn-Phathanothai, L., Ingram, J., Wiebe, K., 2012. A vision for attaining food security. Curr. Opin. Environ. Sustain. 4, 7–17. doi:10.1016/j.cosust.2012.01.008

Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proc. Natl. Acad. Sci. 104, 19680–19685. doi:10.1073/pnas.0701855104

Moyo, D., 2010. Dead Aid: Why Aid Is Not Working and How There Is a Better Way for Africa, 1 Reprint Edition. ed. Farrar, Straus and Girouz.

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R., Vanlauwe, B., 2010. A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. Field Crops Res. 115, 132–139. doi:http://dx.doi.org/10.1016/j.fcr.2009.10.013

Mumford, L., 1964. Authoritarian and Democratic Technics. Technol. Cult. 5, 1. doi:10.2307/3101118

Muthoni, J., Nyamongo, D.O., 2010. Traditional Food Crops and Their Role in Food and Nutritional Security in Kenya. J. Agric. Food Inf. 11, 36–50. doi:http://dx.doi.org/10.1080/10496500903466745

Nhemachena, C., Mano, R., 2007. Assessment of the economic impacts of climate change on agriculture in Zimbabwe : a ricardian approach, Policy Research Working Papers. The World Bank.

Nicholson, S.E., 2001. Climatic and environmental change in Africa during the last two centuries. Clim. Res. 17, 123–144. doi:http://dx.doi.org/10.3354/cr017123

Norgaard, R.B., 1976. Integrating Economics and Pest Management, in: Apple, J.L., Smith, R.F. (Eds.), Integrated Pest Management. Springer US, pp. 17–27.

Norman, D.W., 1967. An economic study of three villages in Zaria Province. Institute for Agricultural Research, Samaru, Ahmadu Bello University.

Nourish, 2014. Food System Tools [WWW Document]. Nourish - Food Community. URL http://www.nourishlife.org/teach/food-system-tools/ (accessed 12.12.14).

Odhiambo, W., Nyangito, H., Nzuma, J., 2004. Sources and determinants of agricultural growth and productivity in Kenya. Kenya Institute for Public Policy Research and Analysis, Nairobi, Kenya.

Oerke, E.-C., 2006. Crop losses to pests. J. Agric. Sci. 144, 31. doi:10.1017/S0021859605005708

Olson, M., 1965. The Logic of Collective Action. Harvard University Press.

One Acre Fund, 2013. AN UPDATE ON ALTERNATIVE CROPS IN KENYA [WWW Document]. One Acre Fund. URL http://www.oneacrefund.org/blogs/tag/sorghum/96 (accessed 5.28.14).

Oram, P.A., 1985. Sensitivity of agricultural production to climatic change. Clim. Change 7, 129–152. doi:http://dx.doi.org/10.1007/BF00139445

Osborn, F.V., Park, G.E., 2002. Community-based Methods to Reduce Crop Loss to Elephants: Experiments in the Communal Lands of Zimbabwe. Pachyderm 33, 32–38.

Osgood, D.E., McLaurin, M., Carriquiry, M., Mishra, A., Fiondella, F., Hansen, J.W., Peterson, N., Ward, M.N., 2007. Designing Weather Insurance Contracts for Farmers in Malawi, Tanzania and Kenya: Final

Report to the Commodity Risk Management Group, ARD, World Bank. International Research Institute for Climate and Society (IRI), Columbia University, New York, NY, USA.

Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action, 1 edition. ed. Cambridge University Press, Cambridge ; New York.

Ouma, J.O., Murithi, F.M., Mwangi, W., Verkuijl, H., Gethi, M., De Groote, H., 2001. Adoption of maize seed and fertilizer technologies in Embu District, Kenya. International Maize and Wheat Improvement Center (CIMMYT), Mexico.

Overholt, W.A., Conlong, D.E., Kfir, R., Schulthess, F., Seétamou, M., 2003. Biological Control of Gramineous Lepidopteran Stem Borers in Sub-Saharan Africa, in: Biological Control in IPM Systems in Africa. CABI.

Pangaribowo, E.H., Gerber, N., Torero, M., 2013. Food and Nutrition Security Indicators: A Review (SSRN Scholarly Paper No. ID 2237992). Social Science Research Network, Rochester, NY.

Peter, G., Runge-Metzger, A., 1994. Monocropping, intercropping or crop rotation? An economic case study from the West African Guinea savannah with special reference to risk. Agric. Syst. 45, 123–143.

Peterson, N.D., 2012. Developing Climate Adaptation: The Intersection of Climate Research and Development Programmes in Index Insurance: Developing Climate Adaptation. Dev. Change 43, 557–584. doi:http://dx.doi.org/10.1111/j.1467-7660.2012.01767.x

Pingali, P.L., Hossain, Gerpacio, R.V., C.A.B. International, International Rice Research Institute, 1997. Asian rice bowls: the returning crisis? CAB International ; in association with the International Rice Research Institute, New York; Manila.

Poulton, C., Kanyinga, K., 2013. The Politics of Revitalising Agriculture in Kenya (Working Paper No. 59). Future Agricultures, Brighton, UK.

Pretty, J.., Morison, J.I.., Hine, R.., 2003. Reducing food poverty by increasing agricultural sustainability in developing countries. Agric. Ecosyst. Environ. 95, 217–234. doi:10.1016/S0167-8809(02)00087-7

Pretty, J., Toulmin, C., Williams, S., 2011. Sustainable intensification in African agriculture. Int. J. Agric. Sustain. 9, 5–24. doi:http://dx.doi.org/10.3763/ijas.2010.0583

Pretty, J., Ward, H., 2001. Social capital and the environment. World Dev. 29, 209–227. doi:10.1016/S0305-750X(00)00098-X

Ralph, J., Helmut, S., Berthold, H., Chris, S., 2006. Farm Management Handbook of Kenya Vol. II, Part C - East Kenya, Subpart C, Eastern Province. Kenyan Ministry of Agriculture, in Cooperation with the German Agency for Technical Cooperation (GTZ), Nairobi.

Rollins, K., Briggs III, H.C., 1996. Moral hazard, externalities, and compensation for crop damages from wildlife. J. Environ. Econ. Manag. 31, 368–386.

Romano, K., 2009. Food Security in Kenya. Republic of Kenya - Ministry of Agriculture, Nairobi.

Rosegrant, M.W., 2003. Global Food Security: Challenges and Policies. Science 302, 1917–1919. doi:10.1126/science.1092958

Ruelle, P., Bruggers, R.L., 1982. TRADITIONAL APPROACHES FOR PROTECTING CEREAL CROPS FROM BIRDS IN AFRICA, in: Proceedings of the Tenth Vertebrate Pest Conference (1982).

Rusinamhodzi, L., Corbeels, M., Nyamangara, J., Giller, K.E., 2012. Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. Field Crops Res. 136, 12–22. doi:http://dx.doi.org/10.1016/j.fcr.2012.07.014

Schmidhuber, J., Tubiello, F.N., 2007. Global food security under climate change. Proc. Natl. Acad. Sci. 104, 19703–19708. doi:10.1073/pnas.0701976104

Sen, A., 1981. Poverty and Famines: An Essay on Entitlement and Deprivation, Reprint edition. ed. The Clarendon Press, Oxford; New York.

Seo, S.N., Mendelsohn, R., 2008a. A Ricardian analysis of the impact of climate change on South American farms. Chil. J. Agric. Res. 68, 69–79. doi:http://dx.doi.org/10.4067/S0718-58392008000100007

Seo, S.N., Mendelsohn, R., 2008b. Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management. Agric. Econ. 38, 151–165. doi:http://dx.doi.org/10.1111/j.1574-0862.2008.00289.x

Seo, S.N., Mendelsohn, R., 2007. Climate Change Impacts On Animal Husbandry In Africa : A Ricardian Analysis, Policy Research Working Papers. The World Bank.

Smucker, T.A., Wisner, B., 2008. Changing household responses to drought in Tharaka, Kenya: vulnerability, persistence and challenge. Disasters 32, 190–215. doi:10.1111/j.1467-7717.2007.01035.x

Snapp, S.S., 1998. Soil nutrient status of smallholder farms in Malawi. Commun. Soil Sci. Plant Anal. 29, 2571–2588. doi:http://dx.doi.org/10.1080/00103629809370135

Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner-Kerr, R., Kanyama-Phiri, G.Y., 2010. Biodiversity can support a greener revolution in Africa. Proc. Natl. Acad. Sci. 107, 20840–20845. doi:http://dx.doi.org/10.1073/pnas.1007199107

Snapp, S.S., Rohrbach, D.D., Simtowe, F., Freeman, H.A., 2002. Sustainable soil management options for Malawi: can smallholder farmers grow more legumes? Agric. Ecosyst. Environ. 91, 159–174.

Songa, J.M., Overholt, W.A., Mueke, J.M., Okello, R.O., 2002. Farmers' perceptions of aspects of maize production systems and pests in semi-arid eastern Kenya: Factors influencing occurrence and control of stemborers. Int. J. Pest Manag. 48, 1–11. doi:http://dx.doi.org/10.1080/09670870110052077

Songa, W.A., Songa, J.M., 1996. On-Farm Trials in the Katumani Mandate Area - Initial Surveys and Establishment (Interim Report No. 1), KARI/ODA NARP II Crop Protection Project. Kenya Agricultural Research Institute, Nairobi.

Stevenson, A., Lindberg, C.A. (Eds.), 2010. New Oxford American dictionary, 3rd ed. ed. Oxford University Press, Oxford ; New York.

Stock, J.H., 2011. Introduction to econometrics, 3rd ed. ed, The Addison-Wesley series in economics. Addison-Wesley, Boston.

Suarez, P., Linnerooth-Bayer, J., 2010. Micro-insurance for local adaptation. Wiley Interdiscip. Rev. Clim. Change 1, 271–278. doi:http://dx.doi.org/10.1002/wcc.37

Tassell, L.W.V., Phillips, C., Yang, B., 1999. Depredation Claim Settlements in Wyoming. Wildl. Soc. Bull. 27, 479–487.

Temper, L., Martinez-Alier, J., 2013. The god of the mountain and Godavarman: Net Present Value, indigenous territorial rights and sacredness in a bauxite mining conflict in India. Ecol. Econ. 96, 79–87. doi:10.1016/j.ecolecon.2013.09.011

Thapa, G., Gaiha, R., 2011. Smallholder farming in Asia and the Pacific: Challenges and opportunities. IFAD Con Ference New Dir. Smallhold. Agri Cult. 24, 25.

The Economist, 2014. Global Food Security Index 2014 - An Annual Measure of the State of Global Food Security. The Economist - Intelligence Unit.

The World Bank, 2013. Kenya | Data [WWW Document]. World Bank Group. URL http://data.worldbank.org/country/kenya (accessed 5.28.14).

The World Bank, 2008. Kenya Poverty and Inequality Assessment - Volume I: Synthesis Report (No. 44190-KE). Poverty Reduction and Economic Management Unit Africa Region, Washington, D.C.

Thierfelder, C., Cheesman, S., Rusinamhodzi, L., 2012. A comparative analysis of conservation agriculture systems: Benefits and challenges of rotations and intercropping in Zimbabwe. Field Crops Res. 137, 237–250. doi:http://dx.doi.org/10.1016/j.fcr.2012.08.017

Thirtle, C., Lin, L., Piesse, J., 2003. The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America. World Dev. 31, 1959–1975. doi:10.1016/j.worlddev.2003.07.001

Tracey, J., Bomford, M., Hart, Q., Saunders, G., Sinclair, R., 2007. Managing Bird Damage to Fruit and Other Horticultural Crops. Australian Government - Bureau of Rural Sciences - Department of Agriculture, Fisheries and Forests, Canberra.

Trimble, S.W., Goudie, A., 2008. Man-induced soil erosion on the southern Piedmont, 1700-1970. Soil and Water Conservation Society, Ankeny, Iowa.

UCLA, n.d. Stata Data Analysis Examples - Logistic Regression [WWW Document]. Inst. Digit. Res. Educ. IDRE UCLA. URL http://www.ats.ucla.edu/stat/stata/dae/logit.htm

UN, 2014. The Millennium Development Goals Report 2014. The United Nations, New York, NY.

UN, 2010. Rethinking Poverty: Report on the World Social Situation 2010. United Nations Department of Economic and Social Affairs.

Van Mil, H.G.J., Foegeding, E.A., Windhab, E.J., Perrot, N., van der Linden, E., 2014. A complex system approach to address world challenges in food and agriculture. Trends Food Sci. Technol. 40, 20–32. doi:10.1016/j.tifs.2014.07.005

Varoufakis, Y., 1998. Foundations of economics: a beginner's companion. Routledge, London ; New York.

Varshney, R.K., Close, T.J., Singh, N.K., Hoisington, D.A., Cook, D.R., 2009. Orphan legume crops enter the genomics era! Curr. Opin. Plant Biol. 12, 202–210. doi:10.1016/j.pbi.2008.12.004

Vatn, A., 2005. Institutions and the environment. Edward Elgar Pub, Cheltenham, UK ; Northampton, MA.

Verchot, L.V., Van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K.V., Palm, C., 2007. Climate change: linking adaptation and mitigation through agroforestry. Mitig. Adapt. Strateg. Glob. Change 12, 901–918. doi:10.1007/s11027-007-9105-6

Verhoef, E.T., 2002. Externalities, in: Handbook of Environmental and Resource Economics. Edward Elgar, Cheltenham, UK; Northampton, MA.

Waddington, S.R., Mekuria, M., Siziba, S., Karigwindi, J., 2007. Long-Term Yield Sustainability and Financial Returns from Grain Legume-Maize Intercrops on a Sandy Soil in Subhumid North Central Zimbabwe. Exp. Agric. 43. doi:10.1017/S0014479707005303

Wagner, K.K., Schmidt, R.H., Conover, M.R., 1997. Compensation Programs for Wildlife Damage in North America. Wildl. Soc. Bull. 25, 312–319.

Weinberger, K., Lumpkin, T.A., 2007. Diversification into Horticulture and Poverty Reduction: A Research Agenda. World Dev. 35, 1464–1480. doi:10.1016/j.worlddev.2007.05.002

Weingärtner, L., 2009. The Concept of Food and Nutrition Security, in: Klennert, K. (Ed.), Achieving Food and Nutrition Security. Internationale Weiterbildung und Entwicklung gGmbH - Capacity Building International, Germany.

Wenny, D.G., DeVault, T.L., Johnson, M.D., Kelly, D., H. Sekercioglu, C., Tomback, D.F., Whelan, C.J., 2011. The Need to Quantify Ecosystem Services Provided by Birds. The Auk 128, 1–14. doi:10.1525/auk.2011.10248

Wilsey, B.J., Potvin, C., 2000. Biodiversity and Ecosystem Functioning: Importance of Species Evenness in an Old Field. Ecology 81, 887–892. doi:10.1890/0012-9658(2000)081[0887:BAEFIO]2.0.CO;2

Wilson, P., Wilson, C., 2006. Make Poverty Business: Increase Profits and Reduce Risks by Engaging with the Poor. Greenleaf Pubns.

Yashiro, M., Duraiappah, A., Kosoy, N., 2013. A Nested Institutional Approach for Managing Bundle Ecosystem Services: Experience from Managing Satoyama Landscapes in Japan, in: Muradian, R., Rival, L. (Eds.), Governing the Provision of Ecosystem Services, Studies in Ecological Economics. Springer Netherlands, Dordrecht, pp. 191–205.

Young, O.R., 2002. The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale. MIT Press.

Zelli, F., 2011. Fragmentation of the global climate governance architecture. WIREs Clim. Change 2, 255–270. doi:http://dx.doi.org/10.1002/wcc.104

Zelli, F., van Asselt, H., 2013. The Institutional Fragmentation of Global Environmental Governance: Causes, Consequences, and Responses. Glob. Environ. Polit. 13. doi:http://dx.doi.org/10.1162/GLEP_a_00180