Food Security, Climate Change Adaptation and Land Use Options for Smallholder Farmers in Malawi

(A Biophysical-Economic Modeling Approach)

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Declaration of oath

Eidesstattliche versicherung

I, **Mutisungilire Francisco Kachulu**, do hereby declare under oath, that I have written the present dissertation on my own and have not used other than the acknowledged sources and aids.

Hiermit erkläre Ich, **Mutisungilire Francisco Kachulu**, an Eides Statt, dass Ich die vorliegende Dissertationsschrift selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Place	**Date**	**Signature**
Hamburg	30/12/2016	………………………………………………

Dedication

To Lizzie, Thumbiko and Tuntufye

"Every man, woman and child have the inalienable right to be free from hunger and malnutrition……' (WFC 1974). But, why do the smallholder farmers still remain hungry even in this 21st Century? They are not lazy people and contrary to literature, they are not illiterate at all. I dedicate this work to them through you (Lizzie, Thumbiko and Tuntufye); with confidence that the edifice that creates such inhuman suffering will be restructured even under the worst probable scenarios.

Summary

The attainment of food security remains an indispensable process to poverty reduction, economic growth and stability. It is a basic necessity and a human right as endorsed by article 25 of the Human Rights Charter. Strangely, millions of families across the globe suffer from hunger, despite streams of policy committments at global, regional and country level to eradicate it. Smallholder farmers who comprise nearly 80% of the Malawian population provide a vivid case study. In 2010, nearly 30% of smallholder farmers were food insecure, 15% were entirely food dependent and 40% lived the below the poverty line. In the midst of such, climate change is expected to exacerbate the already dire situation. This thesis is designed to analyse and provide insights and options that may lead to the eradication of hunger among smallholder farmers in Malawi. The study specifically analyses the role of: a) food governance systems; b) climate adaptation alternatives and land use change; c) crop, market diversification and tobacco substitution; and d) climate mitigation support mechanisms in relation to welfare of smallholder farmers in Malawi.

Chapter one gives the background to the study area, highlighting the current and possible future challenges that smallholder farmers might face. The motivation of the study culminates from combination of the challenges faced by smallholder farmers and the basic necessity to achieve food security. Chapter one ends by highlighting the overall research objectives. Chapter two, deals with data sources and methods. The thesis methodology largely hedges on the development of the Malawi Agricultural Sector Model (MASM). MASM depicts the Malawian agricultural demand and supply side and is adapted or adjusted in subsequent chapters to address specific research questions.

Chapter three discusses the role of alternative food governance systems and policy support mechanisms like input subsidy and market access in hunger eradication. The food governance systems are differentiated as sovereign and dependent. The sovereign system forces all the regions in Malawi to first attain a set minimum food production level before production of cash crops and restrict food export when such minimum levels are not met. The dependent system depicts farmers' free choice to grow any crops in order to maximise income and rely on food imports if the minimum set food requirements are not met. Chapter four focusses on future climate change impacts on crop productivity under different crop technologies from 2010 to 2070. Smallholder farmers are presented with the choice to adapt or not to adapt to climate change and its impact on the agricultural sector. To aid farmers' decision, a welfare sensitivity analysis and optimal land use adaptation options are presented for each decision and in different decades.

Chapter five discusses one of the greatest dilemmas facing policy makers in Malawi. Tobacco is considered the "green gold" of Malawi. It contributes to over, 45% of the farmers' income, 75% of the government total foreign exchange earnings (forex) and 20% of government tax base. However, at global level, there are strong campaigns to curtail tobacco production due to health and environmental concerns. The dilemma arises in taking a policy decision to curtail tobacco without risking welfare and producer revenue losses. Chapter five, therefore analyses potential susbsitute crops to replace tobacco with minimal welfare, producer revenue and forex losses. Chapter six is based on the principle of common but differentiated responsibility under the Kyoto protocol. Smallholder farmers constitute the majority of the population in sub-Saharan Africa and Malawi. Yet, their participation in mitigation targets is not well known or supported. Chapter six thus, analyses technology support mechanisms for smallholder farmers to optimally contribute to mitigation targets without compromising food security targets.

Chapter seven gives general conclusions and recommendations of the thesis. Seeking income maximisation does not necessarily lead to food security. The food sovereign system was found to be more efficient in hunger eradication than the dependent system among smallholder farmers in Malawi. If tobacco is to be curtailed, besides expansion of market opportunities for tobacco susbsitute crops, there should be prior complementary investments from other economic sectors. Otherwise, a curtailing of tobacco would result in huge producer revenue and government forex losses, which would consequently affect the entire Malawian economy. Promotion of environmentally friendly soil based technologies, like conservation agriculture, may not necessarily lead to increased mitigation. Subsidising conservation agriculture prompted farmers to increase cultivated areas which led to reduced fallow areas, and consequently reduced total soil organic carbon abatement. Even though taxes were more effective in soil organic carbon sequestration, they may not be implemented due to their negative effect on producer revenue. Agricultural planners and policy makers need to monitor technology support levels to avert unintended environmental negative consequences.

Zusammenfasung

Die Erreichung der Ernährungssicherheit bleibt ein unverzichtbarer Prozess für Armutsbekämpfung, Wirtschaftswachstum und Stabilität. Ernährungssicherheit ist ein grundlegendes Bedürfnis und ein Menschenrecht, welches durch Artikel 25 der Menschenrechtscharta artikuliert wird. Bedauerlicherweise leiden Millionen von Familien auf der ganzen Welt unter Hunger, trotz vieler politischer Anstrengungen auf globaler, regionaler und auf Landesebene, Hunger zu beseitigen. Kleinbauern, die fast 80% der Malawischen Bevölkerung umfassen, veranschaulichen die Situation. Im Jahr 2010 waren fast 30% der Kleinbauern unzureichend ernährt, 15% waren vollständig abhängig von Lebensmittelzuteilungen und 40% lebten unterhalb der Armutsgrenze. Es wird befürchtet, dass der Klimawandel die schon jetzt schwierige Situation weiter verschärft. Die Analysen der vorliegenden Doktorarbeit sollen Erkenntnisse über Möglichkeiten liefern, die Hungersnot der Kleinbauern in Malawi zu mindern. Konkret analysiert die Arbeit die Bedeutung von: a) Lebensmittelverteilungssystemen; b) Landnutzungsänderungen und klimabedingter Anpassung; c) Sortenwahl und Marktdiversifizierung sowie Alternativen zu Tabakanbau; und d) Maßnahmen zur Unterstützung der Einkommen von Kleinbauern in Malawi.

Kapitel 1 beschreibt das Studiengebiet und hebt die aktuellen und zukünftigen Herausforderungen der Kleinbauern in Malawi hervor. Die Motivation der Studie ergibt sich aus der Kombination von Herausforderungen, denen Kleinbauern ausgesetzt sind und der gesellschaftlichen Notwendigkeit die Ernährung der Bevölkerung zu sichern. Am Ende des ersten Kapitels werden die allgemeinen Forschungsziele hervorgehoben. Kapitel zwei befasst sich mit den Datenquellen und Methoden. Die Methodik der Doktorarbeit ist eng an die

Entwicklung des Malawi Agrarsektormodells (MASM) gekoppelt. MASM simuliert Angebot und Nachfrage der Malawischen Landwirtschaft und wird in den nachfolgenden Kapiteln modifiziert, um spezifische Forschungsfragen zu lösen.

Kapitel drei diskutiert die Rolle alternativer Lebensmittelverteilungssysteme und politischer Instrumente wie Düngemittelsubventionen und Vermarktungsunterstützung für die Ausrottung des Hungers. Die Verteilungssysteme werden in souveräne und abhängige Systeme unterschieden. Das souveräne System zwingt alle Regionen in Malawi, ein festgelegtes Mindestniveau an Nahrungsmittelproduktion zu erreichen und den Export von Lebensmitteln zu beschränken. Das abhängige System erlaubt Landwirten dagegen die freie Wahl der Anbaukulturen, um das Einkommen zu maximieren. Nahrungsmittelimporte dienen in diesem System zur Befriedigung der festgelegten Nahrungsmittelbedürfnisse. Kapitel 4 beschäftigt sich mit den Auswirkungen des Klimawandels auf die Ernteproduktivität verschiedener Anbautechnologien für den Zeitraum 2010 bis 2070. Kleinbauern können sich in verschiedener Weise an den Klimawandel anpassen und beeinflussen dadurch letztlich auch den Agrarsektor. Um die landwirtschaftlichen Entscheidungen besser zu verstehen, werden für jede Entscheidungsoption und für jedes Jahrzehnt Wohlfahrtssensibilitätsanalysen und optimale Anpassung der Landnutzung präsentiert.

Kapitel 5 diskutiert eines der größten Dilemmas für Politiker in Malawi. Tabak gilt als das "grüne Gold" in Malawi. Es trägt zu über 45% der landwirtschaftlichen Einkommen, 75% der Exporteinnahmen und 20% der staatlichen Steuereinnahmen bei. Auf globaler Ebene gibt es jedoch starke Anstrengungen, die Tabakproduktion aufgrund von Gesundheits- und Umweltproblemen zu reduzieren. Das Problem besteht darin, eine politische Entscheidung zu treffen, welche die Tabakproduktion reduziert, ohne die Wohlfahrt und die Einnahmen der Produzenten zu gefährden. Kapitel fünf analysiert daher potenzielle Ersatzpflanzen, um Tabak mit minimalen Verlusten an Wohlstand, Produzenteneinkommen und Exporterlösen zu ersetzen. Kapitel 6 basiert auf dem Prinzip der gemeinsamen, aber differenzierten Verantwortung im Rahmen des Kyoto-Protokolls. Kleinbauern bilden die Mehrheit der Bevölkerung in Sub-Sahara Afrika und Malawi. Dennoch ist ihr Beitrag zur Erreichung der Klimaschutzziele weder bekannt noch gefördert. Kapitel sechs analysiert mögliche technologische Unterstützungen für Kleinbauern, um einen Beitrag zu Emissionsminderungszielen zu leisten, ohne dass die Ernährungssicherheit kompromittiert wird.

Kapitel 7 enthält allgemeine Schlussfolgerungen und Empfehlungen der Arbeit. Die Maximierung des Einkommens führt nicht unbedingt zu Ernährungssicherheit. Das souveräne Nahrungsmittelverteilungssystem ist effizienter in der Ausrottung des Hungers als das abhängige System. Sollte der Tabakanbau gekürzt werden, müssten neben dem Ausbau der Marktchancen für Ersatzpflanzen auch ergänzende Investitionen aus anderen Wirtschaftszweigen erfolgen. Andernfalls würde eine Drosselung der Tabakproduktion zu großen Verlusten der Produzenteneinnahmen und Exporterlöse führen und infolgedessen die Wirtschaft Malawis beeinträchtigen. Die Doktorarbeit schlussfolgert auch, dass die Förderung umweltfreundlicher Anbautechnologien, wie die konservierende Bodenbearbeitung, nicht unbedingt die Emissionen mindert. Die Subventionierung der konservierenden Bodenbearbeitung führte zu einer Steigerung der Gesamtanbaufläche zu Lasten von Brachflächen mit dem Ergebnis einer geringeren organischen Kohlenstoffspeicherung im Boden. Während Technologiesteuern für die Kohlenstoffspeicherung wirksamer sind, haben sie negative Auswirkungen auf die Erzeugereinnahmen und werden daher nicht bevorzugt. Landwirtschaftliche und politische

Entscheidungsträger sollten das Niveau der Technologiesubventionen kontrollieren, um unbeabsichtigte negative Konsequenzen zu vermeiden.

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Abbreviations

ADD	Agriculture Development Division
AR5	The Fifth Assessment Report of the IPCC
ASWAp	Agriculture Sector Wide Approach
AU	African Union
CAADP	Comprehensive African Agriculture Development Programme
CERES	Crop Environment Resource Synthesis
BLADD	Blantyre Agricultural Development Division
CESCR	Committee on Economic, Social and Cultural Rights
EPA	Extension Planning Area
EPIC	Environmental Policy Intergrated with Climate Model
EUFASOM	European Forest and Agricultural Sector Optimisation Model
FISP	Farm Input Subsidy Programme (FISP)
FAO	Food and Agriculture Organisation of the United Nations
GAMS	General Algebraic Modeling Systems
GCM	General Circulation Model
GoM	Government of Malawi
HRU	Homogenous Response Unit
IHS	Intergrated Household Survey Report
IFAD	International Fund for Agricultural Development
IFRI	International Food Research Institute
IPCC	Intergovernmental Panel on Climate Change
KADD	Kasungu Agricultural Development Division

KRADD	Karonga Agricultural Development Division
LADD	Lilongwe Agricultural Development Division
MADD	Machinga Agricultural Development Division
MACE	Malawi Agricultural Commodity Exchange
MASM	Malawi Agriculture Sector Model
MIROC5	Model for Interdisciplinary Research on Climate
MGDs	Malawi Growth and Development Strategy
MZADD	Mzuzu Agricultural Development Division
NCAL	National Census on Agriculture and Livestock
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goals
SADD	Salima Agricultural Development Division
SSA	Sub-Saharan Africa
SVADD	Shire Valley Agricultural Development Division
UN	United Nations
UNHRC	United Nations Human Rights Charter
UNFCC	United Nations Framework Convention on Climate Change
WFP	World Food Programme
WFS	World Food Summit

Chapter 1: General Introduction

1.1 Introduction

This chapter serves as an introduction to the entire thesis. Firstly, the background to the study area is presented followed by a literature review of Malawian agriculture sector. The review highlights the role of the Malawian agricultural sector to the national economy and farmers' livelihoods. The review also discusses the current and possible future challenges that smallholder farmers in Malawi may face. The challenges faced by smallholder farmers coupled with the need to eradicate hunger form the basis for motivation of the thesis. The chapter is concluded with presentation of the general and specific objectives of the thesis.

1.2 Study area

Malawi is located in Southern Eastern Africa (**Figure 1:1**). It lies between 9^{o} 22' S and 17^{o} 03' S with a total area of 120,000 km^2 of which 94,000 km^2 is land area and 24,000km^2 is covered by water. Over 80% of the population are smallholder farmers who mostly rely on agriculture for their livelihoods (GoM 2012a). In 2010, smallholder farmers constituted nearly 2.5 million families, which was equivalent to 12.5 million out of a total population of 14 million in Malawi. Arable land constitutes nearly 45%, (5.4 million hectares) of total land area (Chidanti-Malunga 2011). Smallholder farmers occupy about 4.5 million hectares of land which is unevenly distributed (Chinsinga 2011), resulting in 60% of farmers owning an average of 1.0ha per farming household (GoM 2012a).

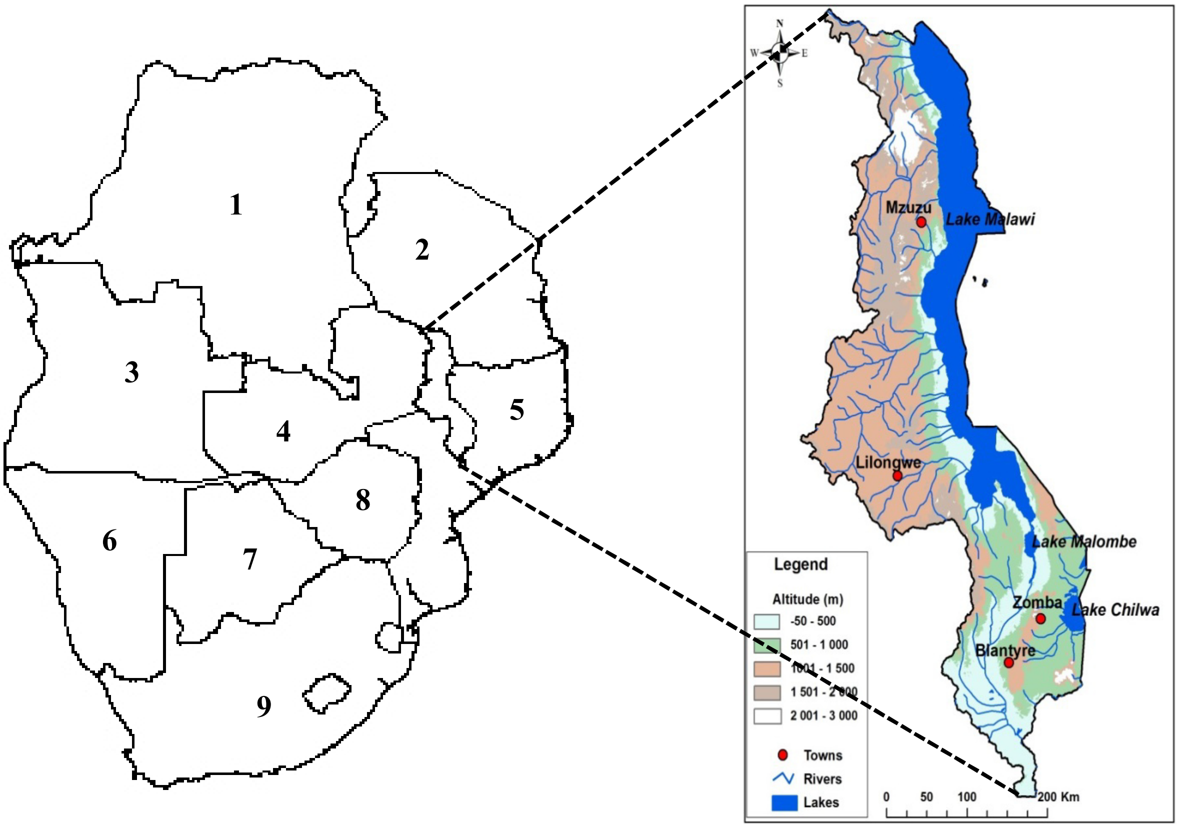


Figure 1:1. Map showing location of Malawi in Southern Africa

Source: map of Malawi (Nhamo *et al.* 2016). 1=DRC, 2 = Tanzania, 3=Angola; 4 = Zambia, 5 = Mozambique, 6= Namibia, 7= Botswana, 8 = Zimbabwe and 9 = South Africa.

Malawi's climate is known to be relatively dry and sub-tropical and seasonal. Temperature varies with altitude ranging from 8^{o}C in the highlands (**Figure 1:2-a**) to 38^{o}C (**Figure 1:2-b**) in the lowlands along the Lake Malawi and the Lower Shire Valley in the southern region. The annual average rainfall also varies with altitude, ranging from 725mm in the lowlands to 2,500mm in the highlands (**Figure 1:2-c**). Effective crop growing rains are usually experienced between the months of November to March (GoM 2006; Nhamo *et al.* 2016). Crop production is heavily dependent on this unimodal rainfed system where over 95% of cultivable land is exclusively rainfed. The rainfed agricultural system renders the country highly vulnerable to the impact of climate change (GoM 2006).

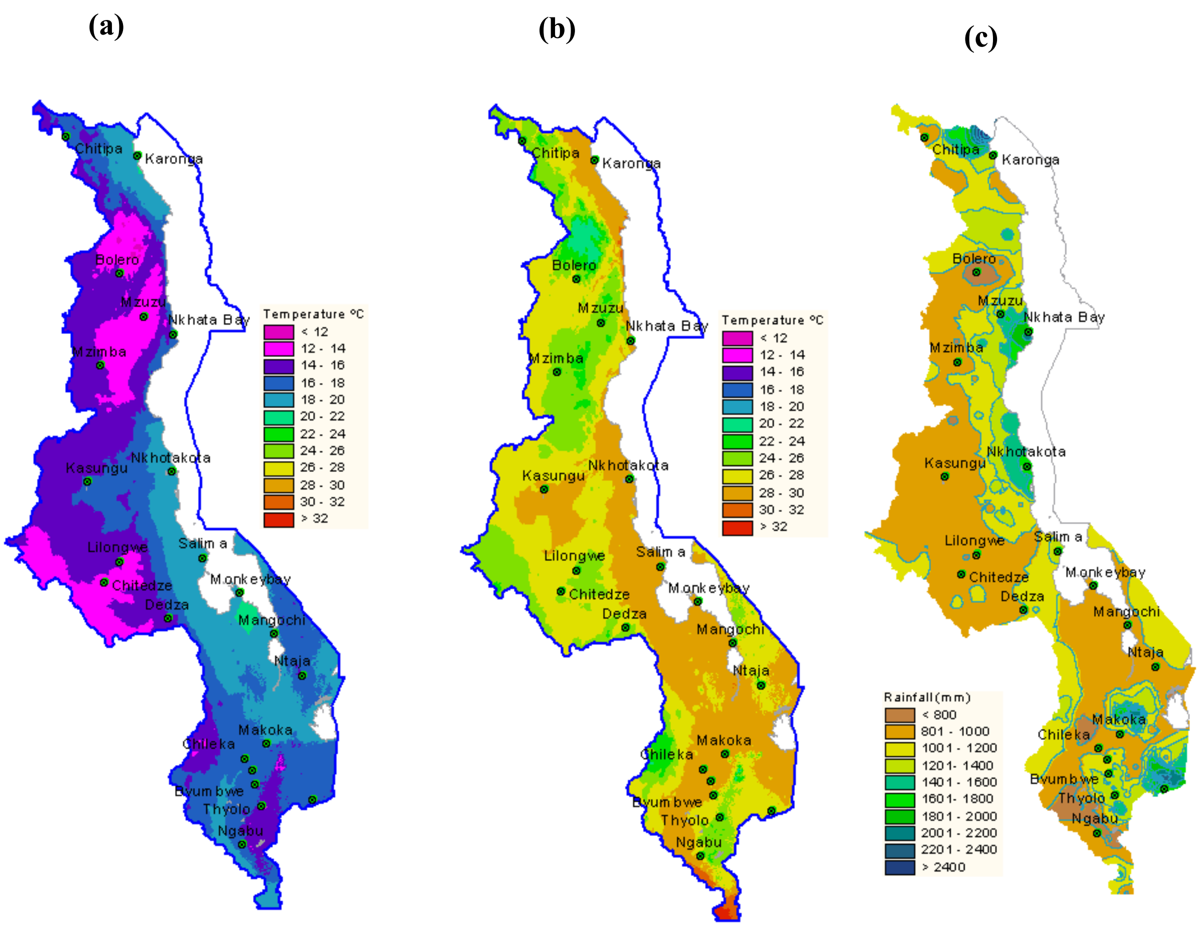


Figure 1:2. Average temperature and rainfall variation in Malawi (2001-2006).
Source: (GoM 2006). (a) = minimum temperature, (b) = maximum temperature and (c) = rainfall

1.3 Role of the agricultural sector in Malawi

Whereas agriculture contributes only 1.8% of GDP and 3% of employment in Europe (Piirto *et al.* 2010), it has a more critical role in many poor countries like Malawi. Since attaining independence in 1964, the agricultural sector has been the cornerstone of national economic growth and development in Malawi. The sector has contributed between 35-40% of the total GDP (GoM 2010b), provided around 85-90% of total employment, 83% of foreign earnings (Tchale 2009) and is the major source of up to 75% of rural income (Chirwa *et al.* 2008). The Malawian agricultural sector is divided in two sub-sectors constituting the smallholder and the estate sector. Smallholder refers to farmers with small land holding sizes less than 5 hectares in Malawi and rely on family manual labour to carry out agricultural activities (Alwang & Siegel 1999; Takane 2008). The estate land holdings sizes range from greater than 5 to thousands of hectares. Only a handful of farmers own land above 1000 hectares and are usually foreign commercial farmers.

While both sub-sectors produce livestock and cash crops, the production of the food crops is most entirely by the smallholder sector. The major cash crops include tobacco, sugarcane, tea, cotton and coffee which account for over 80% of the total forex generation (GoM 2010b). Despite smallholder farmers facing a number of challenges, the smallholder sector contributes 70% to the total agricultural GDP (Tchale 2009). While the current status of the agricultural sector needs transformative adjustments, the view that the agricultural sector in SSA has the highest potential to uplift the majority of the population out of poverty, is agreed upon by many authors (Collier & Dercon 2014; Kydd *et al.* 2004). With fewer opportunities for the population from other economic sectors, the Government of Malawi adheres to this analysis and considers agriculture as a fundamental instrument for sustainable development in the foreseeable future (GoM 2011a; GoM 2010a). Despite this understanding, the smallholder farmers in Malawi still face high incidence of hunger and poverty. In 2015, 40% of the population lived below the poverty line and 32% were described as food insecure (FAO *et al.* 2015), the majority of which were subsistence smallholder farmers.

The food insecurity situation mainly arises due to low production at the household level, and not necessarily from insufficient production at regional or country level. As such, hunger exists even when a particular region may overall produce sufficient food, but access is limited for local consumers due to food exports. This situation has and is currently generating great debate, highlighting the conflict between ethical and economic goals, where populations in producing countries face hunger at the cost of economic efficiency. The debate has generated two schools of thought (Ploeg 2013; Suppan 2003) in what may be classified as sovereign versus dependent food governance systems. A detailed description of the alternative food governance systems is given in Chapter 3.

1.4 Challenges faced by smallholder farmers

1.4.1 Land holding size and ownership

Smallholder farmers in Malawi face many and varied challenges. The major challenge is perhaps to do with the small and fragmented land holding sizes that average 1 hectare per farming household of 5 to 6 people (GoM 2012a). The fragmented land sizes in many countries are known to hinder farm mechanisation adoption as a labour saving technology (Akila & Chander 2009; Chirwa 2004), and at times access to agricultural loans, as land is too small to guarantee surety for the lenders (Hazarika & Alwang 2003). This situation develops into a vicious circle that in turn denies many smallholder farmers, access to markets due to low production levels (Chirwa 2004; Holden *et al.* 2006).

1.4.2 Limited technology adoption

Technology adoption can broadly be distinguished into two categories. The first may be described in terms of crop management practice like subsistence farming or agroforestry system. The management practice among others involves input type and application rate. For instance, subsistence farming (low input system) uses low yielding varieties and low nutrient application rates, whereas intensive farming (high input system) uses high yielding varieties and high nutrient application rates. The second is about the actual technology adoption level which deals with the actual area where a particular farm practice has been adopted.

In terms of fertiliser application, GoM (2014b) reported that only 30% of the total crop area was properly fertilised under smallholder farmers. The low application of fertilisers is mainly due to high poverty levels among smallholder farmers which affect farmers' ability to procure fertilisers. Smale *et al.* (1995) noted that restricted access to fertilizer inputs also prevented farmers from adopting high yield varieties. Among farmers studied by Smale *et al.* (1995), 99% preferred low yielding local varieties to high yielding hybrid varieties. Local varieties were rated by farmers to have better taste and more resistance to weevils than hybrid varieties. The other reason had to do with the performance of improved varieties which was worse than local varieties when there was no fertiliser application.

In regards to technology type, the majority of smallholder farmers practice subsistence farming. This is despite the presence of other, more productive technologies like conservation agriculture, agroforestry systems and intensive farming. While these technologies are clearly more productive when compared to subsistence farming, their adoption is quite low. Ngwira *et al.* (2014), reported that adoption of conservation agriculture was less than 1% of the total cultivated area in Malawi. The relatively high labour costs that arise due to weeding in cases where herbicides are not used and competing needs for energy and animal feed from the crop stover are believed to detract farmers from adopting conservation agriculture (Branca *et al.* 2013; Giller *et al.* 2009). Agroforestry systems are also known to improve soil fertility (Verchot *et al.* 2007) and crop productivity (Albrecht & Kandji 2003; Thangata & Alavalapati 2003). Some types of agroforestry systems like *Falbedia albida* trees may be used by famers for generations (Mfune 2014). Challenges to adoption of agroforestry practices by smallholder farmers include cost of buying tree nurseries, the care of young trees and the problem of trees being tramped or grazed by livestock (Ajayi *et al.* 2007; Kwesiga *et al.* 2003). Intensive farming, which is practiced under irrigation systems, rank among the most productive technologies, however its adoption by smallholder farmers in Malawi is also low at only 16% of cultivated area or 4.2% of the total arable land. This is mainly due to low public investments in irrigation infrastructure (Mangisoni 2008), which renders farmers heavily dependent on rainfed farming. For a country with numerous water resources of up to 20% of the total land, this constitute an underutilisation of irrigation potential (Mangisoni 2008; Nhamo *et al.* 2016) .

1.4.3 Low crop diversification

Lack of crop diversity negatively affects the Malawi economy, smallholder food security and income levels in many ways. Maize is the staple food crop, contributing over 54% of total calorie in Malawian diet (Minot 2010). It is the most monocropped by nearly 97% of smallholder farmers (GoM 2014a; Smale *et al.* 1995) on over 60% of the total cultivated area (GoM 2014a). To switch to more climate resilient crops would require changing food preference of farmers, which has repeatedly proved to be difficult (Dorward & Kydd 2004; Gregory *et al.* 2005). Another major diversity challenge concerns tobacco production. Tobacco has been the sole major export crop accounting for at least 65 to 70% of the export value (Jaffe 2003; Orr & Mwale 2001). Its dominance is linked to relatively high investments in extension services, storage, transportation and marketing infrastructure (Jaffe 2003) when compared to other crops. However, during the past decade, tobacco profitability has been unstably low due to decreasing prices at global market as a result of anti-tobacco campaigns (Jaffe 2003). This situation has resulted in some estates farmers to stop growing tobacco (Tchale 2009). While there has been a growing pressure to effectively ban or reduce tobacco production, the policy dilemma is to make a decision on tobacco curtailing without understanding the effects on smallholder farmers welfare and national economy, or tangible alternative options to minimise the negative effects.

1.4.4 Decreased soil productivity

Most soils under smallholder farmers are heavily degraded in many sub-Saharan African countries (SSA) including Malawi (Davies *et al.* 2010; Munthali & Murayama 2013). The mono-cropping of maize and use of subsistence technology are some of the reasons leading to soil degradation (Kazombo-Phiri 2005; Nakhumwa & Hassan 2012). To restore soil status farmers may choose to adopt technologies which have high potential in soil rehabilitation like conservation agriculture or agroforestry systems (Hobbs 2007; Giller *et al.* 2009; Lal 2006). However, as already outlined, these technologies have low adoption rates among smallholder farmers.

1.4.5 Technology support

Many studies like Branca *et al.* (2013) and Lal (2004a) have suggested that without technology support, most smallholder farmers are unable to adapt to climate change effects by shifting from subsistence farming to alternative technologies. This situation also applies to mitigation participation by smallholder farmers. Soil based technologies unlike the forestry and energy sectors do not have access to REDD+, Joint Implementation and Clean Development Mechanisms programs. Secondly, there is little knowledge in literature on what kind of support mechanism or level would be optimal to support mitigation efforts under smallholder farmers without compromise on food security goals.

1.5 The future scenarios of the agricultural sector

A number of issues currently converge in the agricultural sector that require due consideration for future planning if hunger is to be eradicated. Such factors include population growth and climate change. With the current fertility rate at 5.7 and population growth rate at 3.6% per annum, even when the impact of HIV/AIDS is taken into consideration, the Malawi population is expected to almost triple to 40 million by 2040 (Cohen 2006; GoM 2012a). Such increase has been witnessed before when the Malawi population grew from 4 million in 1966 to 14 million in 2010. The increase in population will have a massive effect on the already stretched land resources. Besides the challenges of population growth, climate change is also acknowledged as the most contemporary challenge of the 21st century. The IPCC fifth assessment report has estimated a temperature rise of between 1-6^{o}C by 2100 (Pachauri *et al.* 2015). The effects of climate change though partially studied in Malawi mainly point to reduced yield crops (Saka *et al.* 2003). In short, the future scenarios will require a paradigm shift in land use in order to feed the growing smallholder farmer population in Malawi.

1.6 Thesis motivation

Motivation for the thesis is presented firstly in general and four specific points which are further detailed under each chapter. The four specific points deal with food governance; climate effects; tobacco substitution; and mitigation options in relation to welfare of smallholder farmers in Malawi.

1.6.1 General motivation

In general, the literature review found no studies which analysed and proposed policy options under which hunger would be eradicated among smallholder farmers within the agricultural sector. The general motivation of this thesis is therefore to analyse conditions and generate knowledge for policy guidance under which hunger among smallholder farmers can be eradicated.

1.6.2 Specific motivation

1.6.2.1 Effect of food governance on hunger

While there are a number of debates on sovereign versus dependent food governance systems, not many studies have analysed the effect of each governance system in relation to hunger or poverty especially among smallholder farmers. Chapter three of the thesis gives insights on the debate, analyses and recommends which system would be most effect in hunger eradication among smallholder farmers in Malawi.

1.6.2.2 Adaptations options for smallholder farmers

A literature review for most of southern African countries, including Malawi, reveals that only a partial or limited analysis regarding geographical resolution, crop and technology diversity has been conducted to understand climate effects on welfare of smallscale farmers as highlighted in **Table 1:1.** Chapter four of the thesis is designed to give a comprehensive analysis, whose results are generated from high resolution biophysical data, covering all major crops under different crop technologies in Malawi.

Table 1:1. Previous studies related to climate change impact on agricultural sector in SSA

Author	Crops analysed										Technologies							Study focus	
	Cass	Cott	Gnut	Maiz	Papr	Rice	Sorg	Soyb	Suga	Toba	CA	FA	IF	OF	SF	MNR	NA	Yield	Welf
Akpalu *et al.* (2008)	✘	✘	✘	✓	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✓	✘	✘	✓	✘
Arndt *et al.* (2012)	✘	✘	✘	✓	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✓	✘	✘	✓	✓
Chabala *et al.* (2015)	✘	✘	✘	✓	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✓	✓	✘
Gama *et al.* (2014)	✘	✘	✘	✓	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✓	✘	✓	✓
Knox *et al.* (2010)	✘	✘	✘	✘	✘	✘	✘	✘	✓	✘	✘	✘	✓	✘	✘	✘	✘	✓	✘
Saka *et al.* (2003)	✘	✘	✘	✓	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✓	✘
Schmid *et al.* (2006)	✓	✓	✓	✓	✘	✓	✓	✓	✓	✘	✘	✘	✓	✓	✓	✘	✘	✓	✘
Zinyengere *et al.* (2014)	✘	✘	✘	✓	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✓	✘	✘	✓	✘

Cass = cassava; Cott = Cotton; Gnuts= groundnuts; Maiz = maize; Papr = paprika; Sorg = sorghum; Soyb = soybean; Suga = sugarcane; Toba = tobacco; CA = conservation agriculture; FA= *Falbedia abilda*; IF = intensive farming; OF = optimum fertilisation; SF = subsistence farming; MNR = manure application; NA = technologies not distinguished i.e. aggregated yield over all technologies; Yield = climate change effect on crop yield; and Welf = climate change effect on welfare of farmers.

1.6.2.3 Options for tobacco substitution

Despite increased global pressure to ban or curtail tobacco production, not many studies have analysed the effect of tobacco substitution on the economy or the welfare of both producers and consumers. For Malawi, the previous studies as portrayed in **Table 1:2** were ex-ante, which means did not incorporate any future expected changes in climate or demand. Though, Tsonga & Mataya (2001), attempted to rank the potential crops to replace tobacco, did not recommend actual crop mix areas for tobacco substitute crops, which is essential to guide farmer or public investments in the sector. None of the previous studies analysed the effect of tobacco substitution on smallholder welfare or government forex. Such issues underpin the public debate and cause policy dilemma on whether and how tobacco may be substituted. Chapter five of this thesis tries to address the gaps observed and offer policy guidance on tobacco substitution.

Table 1:2. Previous studies related to tobacco substitution in Malawi

Author	Type of analysis					
	Welfare effect	Farm Revenue	forex generation	Crop mix options	Future climate effect	Crop ranking
Jaffe (2003)	✘	✓	✘	✘	✘	✘
Nakhumwa *et al.* (1999)	✘	✓	✘	✘	✘	✘
Tsonga & Mataya (2001)	✘	✘	✘	✘	✘	✓

Welfare effect = effect of tobacco substitution on consumer welfare and producer revenue; forex loss = effect on government forex generation; crop mix options = if study gave recommendation on actual crops mix options; climate effect = if study included effect of future climate and biophysical conditions; crop ranking = if study recommended which crops had highest potential to replace tobacco.

1.6.2.4 Mitigation options under smallholder farmers

The other and final policy dilemma considered in this thesis is the question of how to achieve the often contravening goals of food security, soil rehabilitation and mitigation targets. As already noted, most of the soils under smallholders are highly degraded. Adoption of high productive technologies like intensive farming which are necessary to attain food security, would degrade the soils further, whereas adoption of soil restorative technologies like conservation agriculture and agroforestry systems have lower productivity to meet food security requirements. The previous studies as presented in **Table 1:3** have not addressed the issue of technology support mechanisms and their related effects on welfare of smallholder farmers in achieving mitigation targets. Chapter six of the thesis, thus focuses on analysing support mechanisms to provide policy guidance under which soil rehabilitation and mitigation targets may be optimised without compromise on food security.

Table 1:3. Previous studies related to soil organic carbon (SOC)

Author	Research Focus								
	Status of SOC	Crop technology and SOC	Other emissions (energy shift and nutrients application)	SOC and crop productivity	Land use and SOC	Future climate change on SOC	SOC and smallscale farmers	SOC support mechanisms	SOC and farmer welfare
Berazneva *et al.* (2014)	✘	✘	✘	✓	✘	✘	✓	✘	✓
Chan *et al.* (2008)	✘	✓	✘	✘	✓	✘	✘	✘	✘
Cambule (2013)	✘	✘	✘	✘	✓	✘	✘	✘	✘
Lal (2004c)	✓	✓	✓	✓	✓	✘	✘	✘	✘
Muñoz-Rojas *et al.* (2013)	✘	✘	✘	✘	✘	✓	✘	✘	✘
Ngwira *et al.* (2012)	✘	✓	✘	✘	✘	✘	✓	✘	✘
Smith *et al.* (2008)	✓	✓	✓	✓	✓	✘	✘	✘	✘
Soler *et al.* (2011)	✘	✘	✘	✘	✘	✘	✘	✘	✘
Sommer & Bossio (2014)	✘	✘	✘	✘	✘	✓	✘	✘	✘
Walker & Desanker (2004)	✘	✘	✘	✘	✓	✘	✘	✘	✘

1.7 Research objectives

The general research objective is to analyse the conditions under which hunger may be eradicated amongst smallholder farmers in Malawi under changes in climate and population growth.

1.7.1 Specific objectives

1.7.1.1 To analyse the effect on food governance systems on hunger eradication among smallholder farmers in Malawi.

1.7.1.2 To analyse the effect of climate change on crop productivity and welfare of smallholder farmers in Malawi

1.7.1.3 To analyse the effect of tobacco substitution on smallholders farmers welfare, producer revenue and government forex base.

1.7.1.4 To analyse types and level of mitigation support mechanisms that optimise mitigation without compromise on food security goals of smallholder farmers in Malawi.

Chapter 2: Methodology

2.1 Introduction

Having established the background, motivation and objectives of the thesis in chapter one, the focus is now shifted to data sources and methodology followed to achieve the outlined specific objectives. The thesis adopts an integrated biophysical-economic modeling approach to develop the Malawi Agricultural Sector Model (MASM). This chapter highlights the development structure, scope, data sources and the mathematical framework of the MASM. Later on, the model performance is analysed and discussed. The chapter is concluded with a summary on how the MASM may be used to analyse the effect of particular policy decisions on the Malawi agricultural sector.

2.2 Review of integrated assessments

2.2.1 Emergence and definition of integrated assessments

Some policy problems transcend beyond one discipline, and require multidisciplinary approach to reach feasible or acceptable solutions (Hieronymi 2013; Rotmans & Van Asselt 1996), thereby requiring integrated modeling approach. Integrated assessments seek to guide policy decisions, taking into consideration the economic, social and environmental consequences that may arise due to actual or perceived policy decisions (Porter & Rossini 1980). In the agricultural sector, integrated assessments may be traced back to the work of Earl Heady, who first worked on optimisation and evaluation of certain farm level policy decisions on rural development in USA (Heady 1957). The approach followed in this thesis is called, “integrated biophysical-economic modeling”, where the term “biophysical” refers to regional conditions that include climate, soil state, crop and crop technologies. Intergrated biophysical-economic modeling may therefore be defined as coupled utilisation of biophysical and economic numerical models to provide policy insights in the agricultural sector (Jones *et al.* 2016; Wheeler & Von Braun 2013).

2.2.2 Utilisation of integrated assessments

Integrated modeling has become a strong tool among scientists and policy makers following the publication of the Brundtland Report on Sustainable Development (Jones *et al.* 2016). The Brundtland report emphasises on three pillars of sustainability, which include; a) economic, b) social and c) environmental suitability. As such, no single sector is detailed enough to cover all the three pillars individually. This is especially true with the complexity of problems regarding food security, poverty, population growth, resource utilisation and the environment (Jones *et al.* 2016). Thus, integrated modeling has become a useful tool for analysing such challenges.

Integrated modeling is also useful in that traditional field experiments are not usually possible to represent all regions and future time periods. In short, integrated models which are developed through softwares that generate specific sector, time and regional policy recommendations (Penning de Vries & HH vanKropff 1991) have potential to guide policy decision a priori (in advance), while traditional field experiments may not. Examples of such decision support systems include climate models like MOROC (Watanabe *et al. 2011*), crop productivity models like EPIC (Williams 1995), Economic models like GTAP (Hertel 1997), or a combination resulting into bio-physical economic models like GLOBIOM (Havlík *et al.*2011), EUFASOM (Schneider & Schwab 2006) and the Spanish Agricultural Sector Model (Choi *et al.* 2015).

In utilising integrated modeling, two main issues are addressed. These include policy optimisation and policy evaluation (Weyant *et al.* 1996). In policy optimisation, scientist guide policy makers by providing the best alternative to maximise an objective function under certain restrictions. In policy evaluation scientists guide policy makers with a set of outcomes that may arise from different policy decisions. Policy optimisation addresses the *"what should be"* scenarios whereas policy evaluation address the *"what if"* scenarios (Jones *et al.* 2016). This thesis depending on a specific objective adopts either or both analyses.

2.2.3 Classification of integrated modeling

Integrated models may be classified depending on data aggregation which could be bottom-up like EUFASOM (Schneider & Schwab 2006) or top-down like GTAP (Hertel 1997). The second classification describe time period analyses where dynamic refers to analysis over several years (Tol 2002) while static and recursive refer to analysis involving a single or a set of particular years analysed in sequence, respectively (Hediger 2006). The third classification describe the geographical coverage as such global like GLOBIOM (Havlík *et al.* 2011), or regional like RAUMIS (Gömann *et al.* 2007) and DRAM (Helming 2005) or country based in case of (Choi *et al.* 2015). The MASM is country based, bottom-up and dynamic model that depicts Malawian agricultural activities and interacts with the other countries through trade.

2.2.4 Challenges of integrated modeling

Even though integrated modeling may be the only feasible way to analyse future outcomes it also has its own shortfalls (Wossink *et al.* 2001). Many of its shortfalls have to do with data availability for calibration (Just 1993). Data limitations lead modellers to opt for top-down aggregation and generalisation. This may be resolved by use of high resolution data which however require both time and computation power. The extent of data detail is usually related to regional needs and policy questions that require analysis.

2.3 Methodology justification

While a few studies have been done on climate related impacts in SSA and Malawi as already presented (**see chapter one, section 4.1, Table 1:1**), there are a number of gaps that need to be filled for effective policy planning. Such gaps being multidisciplinary, i.e. dealing with population growth, food security and climate change; integrated biophysical-economic modeling approach provides a feasible tool for analysis.

2.4 MASM development

2.4.1 MASM development structure

MASM was developed in one of the Algebraic Modeling Languages (AML) known as the General Algebraic Modeling Systems (GAMS). MASM is an integration a crop biophysical model to a partial economic equilibrium model as in presented in **Figure 2:1.** The model follows a documentation structure similar to the European Forest and Agricultural Sector Optimisation Model (Schneider & Schwab 2006). As already outlined, MASM is a bottom-up, dynamic equilibrium model which depicts resource endowments, crops, crop technologies, agricultural markets, population growth and trade to analyse the effect of different policy decisions or scenarios on the Malawian agricultural sector.

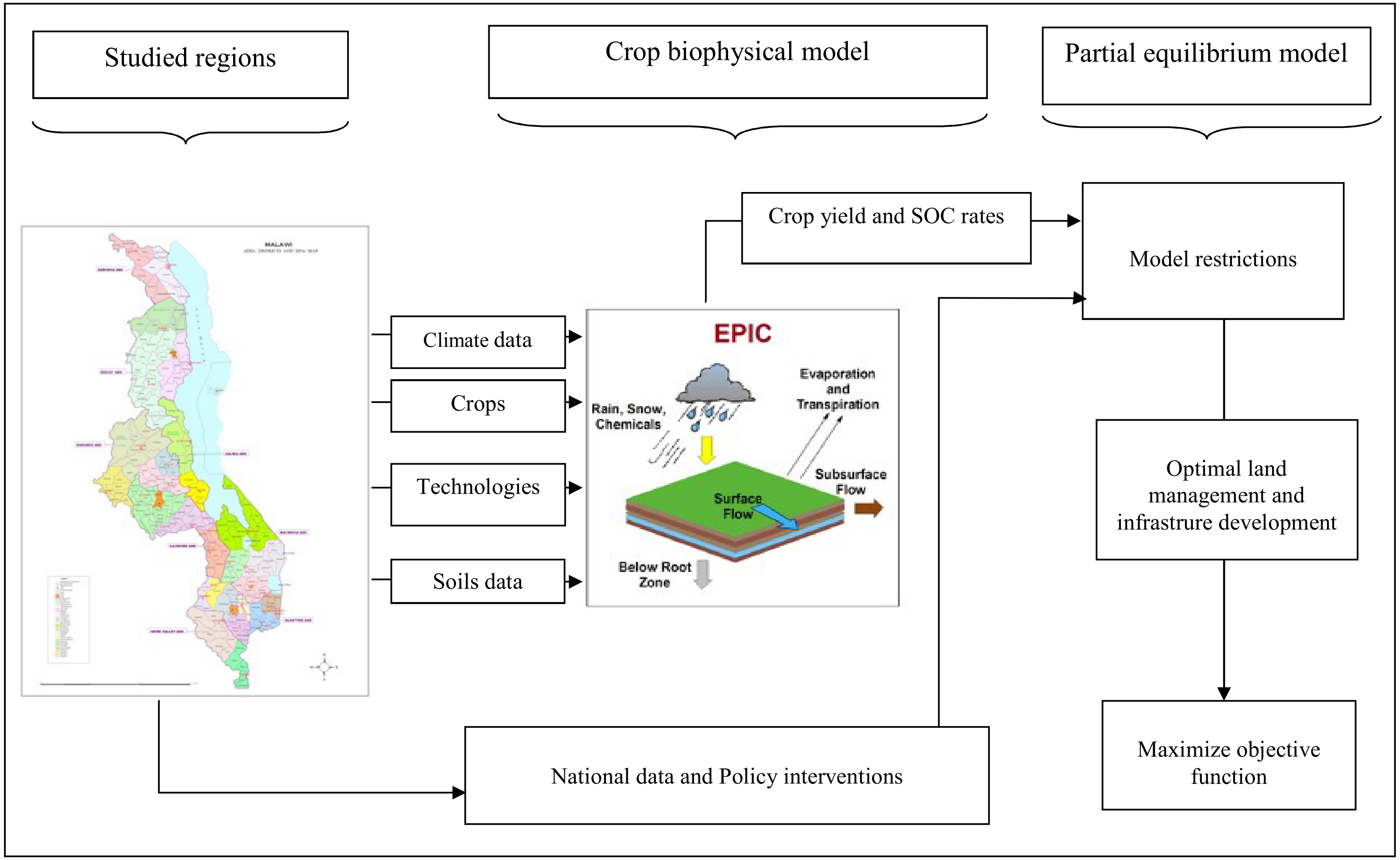


Figure 2:1. Framework for the Malawi Agriculture Sector Model (MASM).

Sources: EPIC diagram (Williams 1995). EPA Map (GoM 1991a). National data = product prices; consumption levels; population; income growth, resource endowments; resource and technology costs data.

2.4.2 MASM indexes, parameters and variables

Table 2:1 highlights the meaning of MASM indexes or sets, while **Table 2:2** highlights MASM parameters or data, and **Table 2:3** highlights MASM variables or outputs.

Table 2:1. Description of MASM indexes

Symbol	Description
b	Fertiliser type
d	Decision: food governance systems (BAU, dependent and sovereign)
	Decision: Choice on tobacco production (continue and curtail tobacco)
	Decision: technology support mechanism (subsidy regime and Tax regime)
j	All crops: cassava, cotton, groundnuts, maize, paprika, rice, sorghum, soybeans, sugarcane and tobacco
	Cash crops (oεj): cassava, cotton, groundnuts, maize, paprika, rice, sorghum, soybeans, sugarcane and tobacco
	Food crops (eεj): cassava, maize, rice and sorghum
	Tobacco substitute crops (xεj): cotton, groundnuts, paprika,, soybeans, and sugarcane
f	Farmer type: Poor farmers (below poverty line) and non poor farmers (above poverty line)
h	Homogenous Response units (HRUs): 1300, which aggregates yield data into EPAs
i	Resource type (arable land and labour)
m	Technology choice: subsistence, conservation agriculture, *Falbedia albida*, optimal fertilisation, and intensive
$r, \tilde{r}$	Studied region: 184 basic analysis units (EPAs), 28 districts, 7 agricultural divisions and 3 administrative regions
s	Intervention type (subsidy or market intervention)
t	Studied period: 2010 to 2070
$\hat{t}$	Historical years: 2005 to 2010
v	Market type: local and external market
z	Intervention level (market, subsidy and tax levels)

Table 2:2. Description of MASM parameters

$\beta_{i,t,r}$	Resource endowment [Total arable land (1000ha) and labour (1000mandays)]
$\alpha_{i,j,m}$	Unit resource used per hectare (ha/ha or man-days/ha)
$\gamma_{j,m,t,r}$	Crop yield (tons/ha)
$ç_{j,m,t,r}$	Unit cost of producing a crop ($/ha)
$ƫ_{j,r,\tilde{r}}$	Unit cost of transporting produce between regions ($/ton)
k_e	Food crop calorific value (Kcalories/ton)
$ş_{j,t,r}$	Unit cost of storing a product per year ($/ton)
ζ_t	Unit cost (emission) or benefit (sequestration) of ton of soil carbon ($/ton),
φ	Daily minimum calorie (2100Kilocalorie/person/day)
$n_{t,r}$	Regional minimum required Giga calories
$\phi_{d,t}$	Cost of Kilocalories ($/Kilocalorie)
$\psi_{d,t}$	Cost of basic necessities ($/t)
$\Psi_{t,r,f}$	Population (1000)
$X_{\hat{t},r}$	Crop mix or historical crop areas
$\eta_{j,m,\hat{t},r}$	Historical crop mix ratio (unit less)
$\hat{Q}_{j,t,r}$	Observed consumption (1000 tons)
$\hat{\rho}_{j,t,r}$	Observed product market prices ($/ton)
Φ_b	Price of fertilizer ($/ha)
$g_{j,m,t,r}$	Soil carbon sequestration rate (tons/ha)

Table 2:3. Description of MASM variables

$C_{t,r}$	Net sequestered soil organic carbon (1000tons)
$L_{e,t,r,m}$	Minimum land required to produce minimum food calories (1000ha)
$L_{j,t,r,m}$	Level of crop activity (1000ha)
$Q_{j,t,r}$	Product demand (1000tons)
$Q^*_{j,t,r}$	Product demand at equilibrium (1000tons)
$P_{j,t,r}$	Product price (\$/ton)
$P^*_{j,t,r}$	Product price at equilibrium (\$/ton)
$T_{j,t,r,\tilde{r}}$	Exported quantity (1000tons)
$T_{j,t,\tilde{r},r}$	Imported quantity (1000tons)
$S_{j,t-1,r}$	Previous storage level (1000tons)
$S_{j,t,r}$	Current storage level (1000tons)
$S^+_{j,t,r}$	Quantity added to storage (1000tons)
$S^-_{j,t,r}$	Quantity subtracted from storage(1000tons)
$\xi_{j,m,t,r}$	Adjustments costs (\$)
W	Objective function (Consumer surplus, (\$)
$\widehat{W}$	Welfare estimated with observed historical crop levels (\$)

2.4.3 MASM scope

MASM covers a sixty year period from 2010 to 2070. The entire country is studied using a bottom-up regional aggregation approach as presented in **Figure 2:2**. 1300 HRUs (**Figure 2:2-a**) were simulated for crop yield and SOC sequestration rates which were aggregated into 184 Agricultural Extension Planning Areas (EPAs), (**Figure 2:2-b**). EPAs represent the smallest and basic administrative planning regions for agricultural activities in Malawi. The model results were estimated for each EPA and aggregated into 28 districts (**Figure 2:2-c**), 8 Agricultural Development Divisions (**Figure 2:2-d**) and then, the entire country. In this way, diversification options were not just estimated at national level but disaggregated into respective agricultural planning regions.

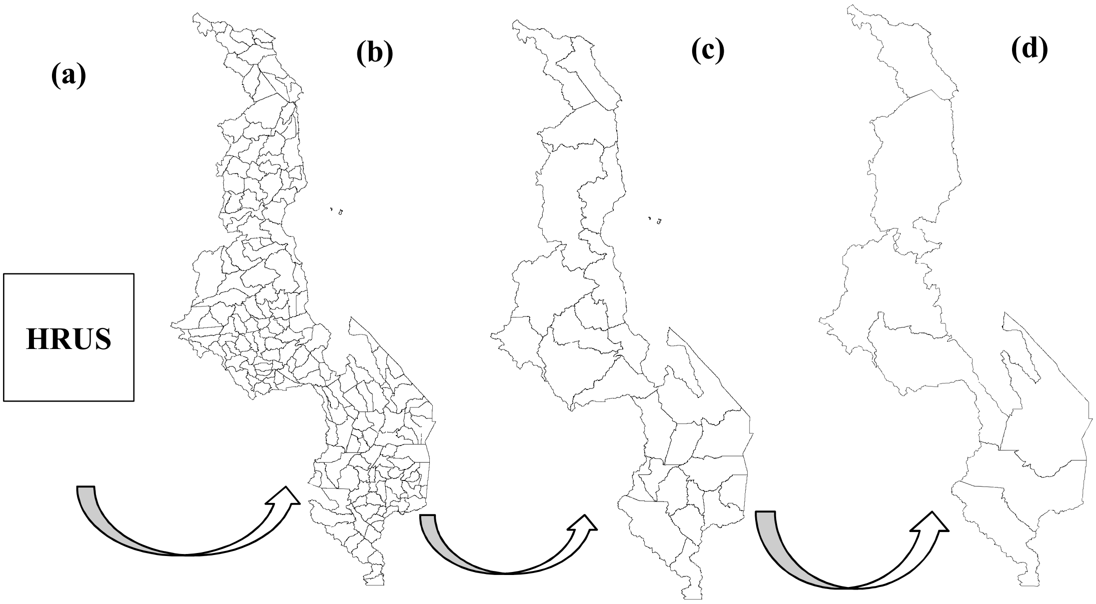


Figure 2:2. Regional data aggregation approach
(a) = 1300 HRUs; **(b)** = 184 EPAs; **(c)** = 28 districts; **(d)** =8 ADDs

2.4.4 Selected crops

Selected crops include cassava, cotton, groundnuts, maize, paprika, rice, sorghum, soybean, sugarcane and tobacco as presented in **Table 2:4.** The selected crops contributed to over 95% of historical crop areas from 2005-2010, (GoM 2014a). From observed data, maize dominated the crop mix accounting for 70% of the total crop cultivated areas, which highlights the subsistence nature of growing one food crop for subsistence needs and problems of crop diversify among smallholder farmers. Even though the selected crops represented over 95% of the cultivated areas, in comparison to total arable land, only 59% of the land was used. This is mainly due to unequal distribution of land among smallholder farmers (Chinsinga 2011) and the tendency to underutilise land among farmers with higher land areas.

Table 2:4. Observed crop area levels

Crop	Cultivated area (000 hectares)	Percent (%) (cultivated /total cultivated area)	Percent (%) (cultivated/total arable land)
Cassava	148.5	5.67	3.35
Cotton	54.32	2.08	1.23
Groundnuts	184.98	7.07	4.17
Maize	1,847.88	70.55	41.6
Paprika	2.85	0.11	0.07
Rice	31.78	1.22	0.72
Sorghum	89.02	3.4	2.01
Soybean	101.53	3.88	2.29
Sugarcane	15.55	0.6	0.35
Tobacco	143.19	5.47	3.23
Totals	**2,619.562**	**100**	**59.02**

Source: Analysed from GoM (2014a) datasets

2.4.5 Selected technologies

Selected crop technologies included subsistence, conservation agriculture, *Falbedia albida*, optimal fertilisation and intensive farming. Subsistence farming represents a technology where, soils are tilled, rainfed dependent, nitrogen applied at 30% than recommended (GoM 2014b). Whereas conservation agriculture represents no tillage, soil cover of atleast 30%, rainfed dependent, nitrogen applied as in subsistence farming but complemented with decomposed biomass from stock cover. *Falbedia albida* is an agroforestry type of technology and depict conditions where soils are tilled, rainfed dependent, nitrogen applied as with subsistence farming but complemented with decomposed biomass from *Falbedia albida* tree leaves. Under optimal fertilisation, soils are tilled, rainfed dependent, nitrogen applied as recommended (GoM 2014b), i.e. no nitrogen stress. With and under intensive farming; soils are tilled, irrigated, nitrogen applied as recommended by (GoM 2014b), i.e. no water and no nitrogen stress.

The observed technology mix by smallholder farmers is presented in **Table 2:5**. Farmers were noted to be heavily reliant on subsistence technology which was practised on nearly 60% of total cultivated area. Despite low adoption rates, conservation agriculture and *Falbedia albida* were selected based on increased promotion from non-governmental organisations in Africa (Giller *et al.* 2009). These technologies are viewed as novel and having co-benefits of high crop productivity and soil organic carbon sequestration when compared to subsistence farming (Branca *et al.* 2013; Hobbs 2007; Umar *et al.* 2011).

Table 2:5. Observed technology mix levels

Technology	Cultivated area (1000 hectares)	Percent (%) (cultivated /total cultivated area)	Percent (%) (cultivated/ total arable land)
Conservation agriculture	12.54	0.48	0.29
Falbedia albida	12.42	0.48	0.29
Intensive farming	110.02	4.2	2.48
Optimal fertilisation	912.99	34.86	20.55
Subsistence farming	1,571.52	60.00	35.38
Fallow*	0.00	0.00	40.0
Totals	**2,619.562**	**100**	**100**

Fallow* = uncultivated area within the total arable land. Source: Analysed from GoM (2014a) datasets

2.4.6 Crop and crop technology simulation combinations

Crop and crop technology combinations for biophysical simulation are presented in **Table 2:6**. Due to unavailability of observed data for calibration or practicability of certain crop technology combinations, only feasible crop technology combinations were simulated.

Table 2:6. Crop and technology simulation combinations

Crop	Technology type				
	Conservation agriculture	*Falbedia albida*	Optimal fertilisation	Intensive farming	Subsistence farming
Cassava	✘	✘	✓	✓	✓
Cotton	✘	✘	✓	✓	✓
Groundnuts	✘	✘	✓	✓	✓
Maize	✓	✓	✓	✓	✓
Paprika	✓	✓	✓	✓	✓
Rice	✘	✘	✓	✓	✓
Sorghum	✓	✓	✓	✓	✓
Soybean	✓	✓	✓	✓	✓
Sugarcane	✘	✘	✓	✓	✓
Tobacco	✘	✘	✓	✓	✓

✓ = simulated crop and technology combinations, ✘ = not simulated due to missing observed data for calibration

2.4.7 Data sources

Data on national population, farming population, population growth, and income levels were sourced from the Intergrated Household Survey (GoM 2012a) and National Census on Agriculture and Livestock (GoM 2012b). Historical EPA crop areas and crop yield data, districts consumption levels and product prices for 2010 were sourced from the Department of Agro Surveys (GoM 2014a) and the Malawi Agricultural Commodity Exchange (MACE 2014). The soil data were sourced from the Department of Land Resources and Conservation through the Land Resource Evaluation Project Database (GoM 1991b). The study uses the worst climate change scenario of RCP8.5 in order to analyse options that guarantee hunger eradication at worst scenarios. Upon review by Gama *et al.* (2014) MIROC 5 was found to be the best GCM, among 15 evaluated GCMs in replicating Malawi climate observed data. On this basis MIROC5 was chosen for the study. The climate data with daily precipitation, maximum, minimum temperature and relative humidity, downscaled from MIROC RCP 8.5 using self-organized maps (Hewitson

& Crane 2006) was provided by the Climate Systems Analysis Group of the University of Cape Town.

2.4.8 Biophysical modeling

2.4.8.1 Crop model selection

The Environmental Policy Integrated Climate (EPIC) model (Williams 1995), was selected for two basic reasons. Firstly, unlike some crop models which are developed for specific crops like CERES for Maize and wheat (Ritchie *et al.* 1989) or SOYGRO for soybeans (Jones *et al.* 1989), EPIC has capabilities to simulate multiple crops. Secondly, EPIC has previously been widely used on climate crop impact studies in SSA (Adejuwon 2005; Schmid *et al.* 2006). EPIC functions in daily time steps and simulates crop growth by predicting the combined effects of crop technologies, water and nutrient availability in the soils. The leaf solar radiation interception is converted into ground and above ground biomass, from which the economic yield is deduced as a product of crop biomass and harvest index.

2.4.8.2 Aggregation of crop yield and SOC rates

The Homogenous Response Unit (HRU) concept (Schmid *et al.* 2006), where an area with same soils, particular slope and altitude range is considered homogenous, was adopted. Crop technologies and climate data were coupled to HRUs to determine distinct crop simulation units. The average EPA crop yield ($\bar{\gamma}_{j,m,t,r}$) was estimated (**eq. 2:1**) as a product of HRU yields ($\gamma_{j,m,t,r,h}$) and HRU areas ($L_{t,r,h}$) divided by respective EPA areas ($\sum_h L_{t,r,h}$). Where (*j*) is crop type, (m) is crop technology option, (*t*) is time period and (*h*) is HRU.

$$\bar{\gamma}_{j,m,t,r} = \sum_{h} (\gamma_{j,m,t,r,h} \, . \, L_{t,r,h}) \Big/ \sum_{h} L_{t,r,h} \qquad \forall_{j,m,t,r} \qquad \textbf{(eq. 2:1)}$$

The EPA SOC rates ($\bar{g}_{j,m,t,r}$) were determined (**eq. 2:2**) as a product of HRU SOC rate ($g_{j,m,t,r,h}$) and respective HRU areas ($L_{t,r,h}$) divided by respective EPA areas ($\sum_h L_{t,r,h}$).

$$\bar{g}_{j,m,t,r} = \sum_{h} (g_{j,m,t,r,h} \, . \, L_{t,r,h}) \Big/ \sum_{h} L_{t,r,h} \qquad \forall_{j,m,t,r} \qquad \textbf{(eq. 2:2)}$$

2.4.9 Partial economic modeling

2.4.9.1 MASM mathematical structure

In MASM, all variables are endogenous and non-negative, except for the objective function ($\boldsymbol{W}$) and net sequested soil organic carbon ($C_{t,r}$) which may be positive or negative. The variables are estimated at optimal levels of agricultural activity, where economic and technological conditions are at equilibrium.

2.4.9.2 The Objective function

The objective function (W) (**eq. 2:3**) estimates the consumer welfare at which all endogenous variables are optimal. It is summed up as the product of consumption ($Q_{j,t,r}$) and market prices ($p_{j,t,r}$), over all crop products (j), study periods (*t*) and regions (*r*) plus the value of outstanding storage ($p_{j,t,r} \, . S_{j,t,r}$) minus the costs of production ($ç_{j,m,t,r} \, . L_{j,m,t,r}$), costs of trade ($ţ_{j,r,\tilde{r}} \, . T_{j,t,r,\tilde{r}}$), storage costs, ($ş_{j,t,r} \, . S_{j,t,r}$), costs or benefit of emission or abatement in terms of soil organic carbon ($\zeta_t \, . \, C_{t,r}$) and costs of calibration adjustments ($\xi_{j,m,t,r} \, . L_{j,m,t,r}$).

$$Max\ W = \sum_{t} \left(\begin{array}{c} \sum_{j,r} \left[\int p_{j,t,r}\ (Q_{j,t,r}) dQ_{j,t,r} \right] \\ + \sum_{j,r} (p_{j,t,r} \cdot S_{j,t,r}) \\ - \sum_{j,m,r} (\text{ç}_{j,m,t,r} \cdot L_{j,m,t,r}) \\ - \sum_{j,\tilde{r},r} (\text{ʈ}_{j,r,\tilde{r}} \cdot T_{j,t,r,\tilde{r}}) \\ - \sum_{j,r} (\text{ş}_{j,t,r} \cdot S_{j,t,r}) \\ - \sum_{r} (\zeta_{t} \cdot C_{t,r}) \\ - \sum_{j,m,r} (\xi_{j,m,t,r} \cdot L_{j,m,t,r}) \end{array} \right) \quad \textbf{(eq. 2:3)}$$

2.4.9.3 Model constraints

2.4.9.3.1 Commodity balance constraints

The commodity balance equation **(eq. 2:4)** ensures that the sum of consumption ($Q_{j,t,r}$), exports ($T_{j,t,r,\tilde{r}}$) and quantity that is added to storage ($S^{+}_{j,t,r}$) do not exceed the sum of production ($\gamma_{j,t,r,m} \cdot L_{j,t,r,m}$), imports ($T_{j,t,\tilde{r},r}$) and quantity subtracted from storage ($S^{-}_{j,t,r}$):

$$Q_{j,t,r} + \sum_{\tilde{r}} T_{j,t,r,\tilde{r}} + S^{+}_{j,t,r} - \sum_{m} (\gamma_{j,t,r,m} \cdot L_{j,t,r,m}) - \sum_{\tilde{r}} T_{j,t,\tilde{r},r} - S^{-}_{j,t,r} = 0 \qquad \forall_{j,t,r} \quad \textbf{(eq. 2:4)}$$

2.4.9.3.2 Resource constraints

Availability of arable land and labour restrict agricultural activities or variable levels **(eq. 2:5)**. The sum product of unit resource use ($\alpha_{i,j,t,r,m}$) and activity level ($L_{j,t,r,m}$) may not exceed resource endowments ($\beta_{i,t,r}$) in each region (*r*) and study periods (*t*):

$$\sum_{j,m} \left(\alpha_{i,j,t,r,m} \ . \ L_{j,t,r,m}\right) \leq \ \beta_{i,t,r} \qquad \forall_{i,t,r} \qquad \textbf{(eq. 2:5)}$$

2.4.9.3.3 Crop mix restrictions

Farmers' decisions are further constrained by a crop mix equation **(eq. 2:6)** which forces all activity levels ($L_{j,t,r,m}$) to fall within a convex combination of historical crop ratios ($\eta_{j,\hat{t},r}$) and historical crop levels ($X_{\hat{t},t,r}$) (Chen & Önal 2012):

$$\sum_{m} L_{j,t,r,m} \ - \sum_{\hat{t}} (\ \eta_{j,\hat{t},r} \ . \ X_{\hat{t},t,r}\ ) = 0 \qquad \forall_{j,t,r} \qquad \textbf{(eq. 2:6)}$$

2.4.9.3.4 Storage level

The outstanding product storage level ($S_{j,t,r}$) (**eq. 2:7**) is the sum of the previous storage level ($S_{j,t-1,r}$) and the current quantity added to storage ($S^{+}_{j,t,r}$) minus the quantity subtracted from storage ($S^{-}_{j,t,r}$):

$$S_{j,t,r} = \ S_{j,t-1,r} + \ S^{+}_{j,t,r} - \ S^{-}_{j,t,r} \qquad \forall_{j,t,r} \qquad \textbf{(eq. 2:7)}$$

2.4.9.3.5 Net sequestrated soil organic carbon

The amount of SOC abatement ($C_{t,r}$) in (**eq. 2:8**) is the product of SOC sequestration rate ($\bar{g}_{j,m,t,r}$) and crop area ($L_{j,t,r,m}$) plus product of fallow sequestration rate ($\bar{g}_{"fallow","fallow",t,r}$)

and fallow area ($\beta_{"land",t,r} - \sum_{j,t,r,m} L_{j,t,r,m}$), summed over all crops (j), management options (m):

$$C_{t,r} = \sum_{j,m,} (\bar{g}_{j,m,t,r} \ . \ L_{j,t,r,m}) + \left(\bar{g}_{"fallow","fallow",t,r} \cdot (\beta_{"land",t,r} - \sum_{j,m} L_{j,t,r,m}) \right) \qquad \forall_{t,r} \qquad \textbf{(eq. 2:8)}$$

2.4.9.3.6 Minimum food requirements

Depending on a policy decision, additional restrictions for minimum food production and consumption is added to the model. The minimum food requirement is achieved in two steps. Firstly, the model ensures that there is enough food produced within each region. This is estimated as a product of crop yield ($\gamma_{e,t,r,m}$), respective crop caloric values (k_e) and a certain level of area allocated to food crops ($L_{e,m,t,r}$) (**eq. 2:9**). Secondly, the model ensures that minimum food consumption level ($Q_{j,t,r,d} \cdot \kappa_e$) is guaranteed in each region before exportation of food crops (**eq. 2:10)**. Based on estimation by Ecker & Qaim (2011) the selected food crops (maize, sorghum, rice and cassava) are assumed to provide at least 80% of the minimum calorie requirement. The minimum daily calorie requirement per person [$\varphi = 2100$Kcalories (Appel 1980)].

$$\sum_{e,m} (\kappa_e \ . \gamma_{e,t,r,m} \ . L_{e,t,r,m}) \geq \ 365\varphi \ . \ \Psi_{t,r} \qquad \forall_{t,r} \qquad \textbf{(eq. 2:9)}$$

$$\sum_{e} (Q_{e,t,r} . \ k_e) \geq 365\varphi \ . \ \Psi_{t,r} \qquad \forall_{t,r} \qquad \textbf{(eq. 2:10)}$$

2.4.10 Model calibration

Model calibration is an adjustment of particular parameters in order to reproduce a response accuracy specified by some criteria (Refsgaard & Henriksen 2004). The model was calibrated by adjusting production costs. Particularly the parameter ($\xi_{j,t,r,m}$) **(eq. 2:11)**, which is equal to the shadow price of restrictions, which when added to the production costs will force the model to replicate observed historical crop activity levels ($\hat{L}_{j,t,r,m}$). In this way there is no deviation from observed welfare ($\partial\widehat{W}$). While highlighted here separately, the cost of adjustments in all scenarios is captured within the production costs.

$$\xi_{j,t,r,m} = \frac{\partial\widehat{W}}{\partial\hat{L}_{j,t,r,m}} \qquad \forall_{j,t,r,m} \qquad \textbf{(eq. 2:11)}$$

2.4.11 Model validation report

In this section, the model validation report is presented as in **Table 2:7.** The validated results are presented for the base year i.e. 2010. The model performance is estimated as model solution outputs in relation to observed levels. For crops areas, the model performance ranges from 92.9% under tobacco to 99.6% under cotton and cassava, resulting in average performance of 96.6%. While consumption levels were for both national and foreign, only national consumption is presented for comparison. Crops like tobacco and paprika are mostly produced for external markets and therefore were assumed to have a zero consumption level in Malawi. The model performance for consumption ranged from 82.74% for sugarcane to 99.21% for Maize and represented an average model performance of 94.3%.

Table 2:7. MASM calibration report

Crop	Crop areas levels (Million hectares)		Model performance (%)	Crop consumption levels (Million tons)		Model Performance (%)
	Observed	Model		Observed	Model	
Cassava	0.1632	0.1625	99.6	2.012	2.335	86.18
Cotton	0.063	0.0627	99.6	0.016	0.017	90.4
Groundnuts	0.1853	0.1915	96.8	0.064	0.061	93.68
Maize	1.9018	1.9953	95.4	1.683	1.697	99.21
Paprika	0.003	0.0031	95.1	0.000	0.000	100.00
Rice	0.0378	0.0353	92.9	0.069	0.071	97.58
Sorghum	0.1015	0.1019	99.7	0.051	0.053	95.86
Soybean	0.1238	0.1286	96.4	0.049	0.048	97.43
Sugarcane	0.0165	0.0162	98.3	0.076	0.065	82.74
Tobacco	0.1065	0.1146	92.9	0.000	0.000	100.00
Average model performance			**96.6%**			**94.3%**

2.5 Conclusion

In this chapter, a justification of the methodology to properly answer the stated objectives has been given. The Malawi Agricultural Sector Model (MASM) which couples a crop biophysical and partial economic equilibrium model was developed as the base methodology upon which specific objectives would be analysed. The chapter has also presented and discussed MASM performance, where MASM is able to realistically replicate observed data. In the preceding chapters, MASM is adapted to analyse policy effect in the agricultural sector of Malawi especially as regards policy changes in food governance systems; the impact of climate change on smallholder farmer welfare; implications of tobacco substitution on welfare and national economy and lastly, type and level of support mechanism to optimally achieve food security and mitigation targets among smallholder farmers in Malawi.

Chapter 3: Effect of Food Governance Systems on Food Security and Welfare of Smallholder Farmers in Malawi

Abstract

Using an integrated biophysical economic modeling approach, the efficiency of alternative food governance systems in eradicating hunger among resource poor smallholder farmers in Malawi is analysed. Results indicate that a sovereign food governance system, which prioritizes regional food production over income maximization, is more efficient in eradicating hunger than a dependent food governance system, whose preference is on production of most economic efficient crops in a region. The findings highlight the need to promote an appropriate food governance system and offer specific farmer group targeted subsidy and market interventions in order to eradicate hunger among resource poor smallholder farmers in Malawi.

Keywords: hunger eradication, agricultural subsidies, market intervention, integrated modeling

3.1 Introduction

For several decades, hunger has been the subject of numerous global and national efforts. Despite several commitments, as of 2010, nearly 23% of the SSA and 32% of the Malawian population were food insecure (FAO *et al.* 2015). Hunger among smallholder farmers is caused by a number of factors including the overdependence on inefficient conventional technologies (Babu & Sanyal 2007; Salami *et al.* 2010), market barriers (Chirwa *et al.* 2008; Kherallah *et al.* 2002), as well as the type of food governance system a country adopts (McKeon 2011; Ploeg 2013).

In general, food governance systems can broadly be distinguished as dependent or sovereign. The dependent system is where regions or countries with high comparative advantage are expected to produce and supply food to all, whereas the sovereign governance system or food based system prioritises the production of enough culturally accepted food before exports of food products or production of cash crops (Pimbert 2009). Each of these food systems as highlighted later in the literature review (**section 3.2.3**) has its own advantages and disadvantages.

While the effects of inefficient conventional technologies and market barriers on hunger have been extensively studied, the effect of food governance on the same has received less attention. Besides analysing the effect of food governance system in hunger eradication, this chapter also analyses the effect of seeking to eradicate hunger on land use changes. This link, of food governance and land use has rarely been addressed in previous studies. Most studies on land use focus on crop productivity (Gama *et al.* 2014; Saka *et al.* 2003), farmer income levels and national economies (Akpalu *et al.* 2008). This chapter is designed to fill the highlighted gaps and offer policy guidance on which food system is best suited to eradicate hunger among smallholder farmers and the associated land use effects in Malawi.

3.2 Literature review

3.2.1 Food crisis and history

Food has greatly shaped the world events in the past. Historical tales of food crisis include the biblical story when Joseph was governor of Egypt around 1700BC (Tainter 2000); the food related strikes under emperor Claudius of Rome in AD51 (McKeon 2011); astronomic food prices leading to the French Revolution in 1879 (White 1995); the Sahelian Food Crisis in the 1970s (Berry 1984); the regional food related strikes of 2007 and 2008 (Berazneva & Lee 2013) and most recently the Arab Spring Uprising in 2010 where food supplies are considered by many authors to have contributed to the revolution (Ansani & Daniele 2012; Hussain & Howard 2013). As such, its role in politics must take central stage to ensure stability and development.

3.2.2 Right to food and food security

Even though, the right to food and food security are known to be technically different terms (Mechlem 2004), many analysts agree that the two have considerable similarities and are usually complimentary (Godfray *et al.* 2010; Schlenker & Lobell 2010). The right to food came into limelight in 1948 when it was included as a human right under the Human Rights Charter. By definition, it refers to a situation where everyone has the physical and economic access to food at all times in adequate quantity and quality (Mechlem 2004). On the other hand, the formal definition of food security was defined following the first World Food Summit in 1974. Food security refers to a situation when all people at all times have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 1996). The differences between the two arise in that the right to food is a legal concept while food security is a policy concept. Secondly they differ at the level of achievement. While food security may be attained at global, regional, country or household level, the right to food may only be attained at individual level (Mechlem 2004). Like any right, the right to food requires that governments commit to a) none interference to its realisation, b) protect its citizens from interference by groups or corporations and c) promote the realisation of the right. In this thesis and specifically on this chapter, food security is viewed as a means to achieve the right to food. In some instances the terminologies are used synonymously.

3.2.3 Dimensions of food security

In brief, food security has four dimensions (Gross *et al.* 2000; Timmer 2012) as shown in **Figure 3:1**. The first dimension deals with production which ensures sufficient food supply either through local production or imports. Production is easily estimated as minimum food required to feed a certain population in a particular administrative region. The second dimension is actual access, which is estimated through food price, income and per-capita food consumption. The third is utilisation which deals with the health care and food preparation processes (Pinstrup-Andersen 2009). The last is stability, which addresses stability aspects of production, access and utilisation. This thesis is rather focussed on hunger aspects of food security, which deal with production and access of calorific or dietary energy requirements. This selection is justified in two ways. Firstly, hunger is the primary and major component of food security and secondly is the major food security component facing SSA and Malawi.

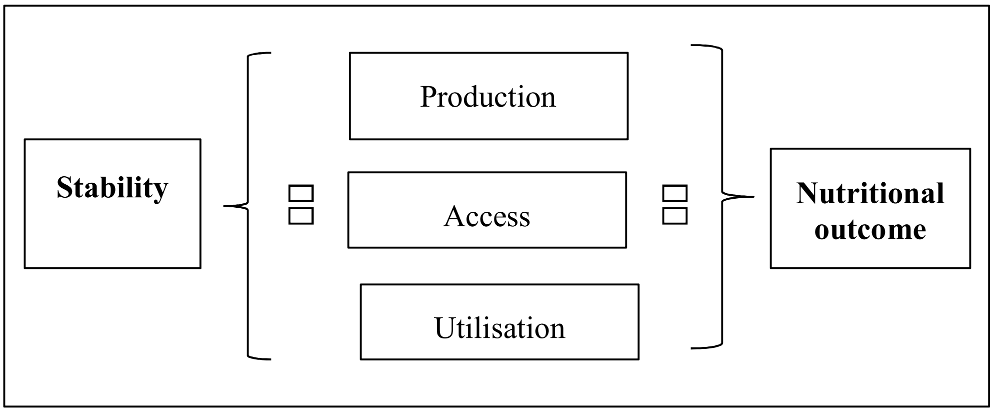


Figure 3:1. Diagrammatic outline of food security dimensions

3.2.4 Food policy commitments and food security status

Since the end of the Second World War, the world has witnessed a number of consented efforts on food production, distribution and access. The UN Food and Agricultural Organisation (FAO) was established in 1947 with a goal to end world hunger. When the United Nations Human Rights Charter (UNHRC) was adopted in 1948, food was included as a human rights issue under section 25 of the charter. The UN efforts were further followed with the establishment of the World Food Programme in 1961, mainly to distribute surplus food to deficit countries. Surplus food was by then, a major problem in developed countries especially the USA (Shaw 2007). In 1974, another UN based organisation the International Fund for Agricultural Development was founded to fund agricultural projects in developing countries with a goal to alleviate rural poverty and improve nutrition.

The "Rome Declaration" was an outcome of the World Food Security Conference (WFS) in 1996 which committed to half the number of hungry people of 1990 levels by 2015. This commitment was later adopted at the Millennium Summit in the year 2000, in what came to be known as MDG1 (Mechlem 2004). Since September of 2015, the target of halving the number of the hungry under MDG1 has been revised in SGD1 to hunger eradication by 2030. Besides the global commitments, reciprocal initiatives have also been witnessed in both Africa and Malawi. At African Union, member states adopted the Comprehensive African Agriculture Development Programme (AU 2006); to propel investments in agriculture that would spur economic growth. The Malabo Declaration was adopted later in 2014 with a goal to eradicate hunger in Africa by the year 2025 (AU 2015). At country level, Malawi food security policy commitments include the National Agricultural Policy of 1982, revised in 1996 and 2016; Poverty Reduction Strategy Paper of 1998, revised 2002; Agricultural Sector Wide Approach (GoM 2011a); Malawi Growth and Development Strategy (GoM 2011b); revised 2011; Malawi Vision 2020 (Nampota *et al.* 2009). Even though with different time frame, all these policy initiatives seek to eradicate hunger much earlier or latest by the year 2030.

Despite the many political commitments, little progress has been made towards food security. Such ambitious political commitments which seek to *"relegate hunger and poverty to the limbo* *of the past"* have rarely materialised (Orr 1966). This has prompted some authors like Shaw (2007) to describe such policies as "*graveyard aspirations*". Indeed, as of 2010 (**Figure 3:2**), nearly 15% of global population, 23% of SSA population and 32% of Malawian population were food insecure (FAO *et al.* 2015). While the graph, presents considerable decrease in terms of proportion of the hungry, the absolute number of the hungry people has increased from 450 million in 1990 to 850 Million in 2014 (FAO *et al.* 2015).

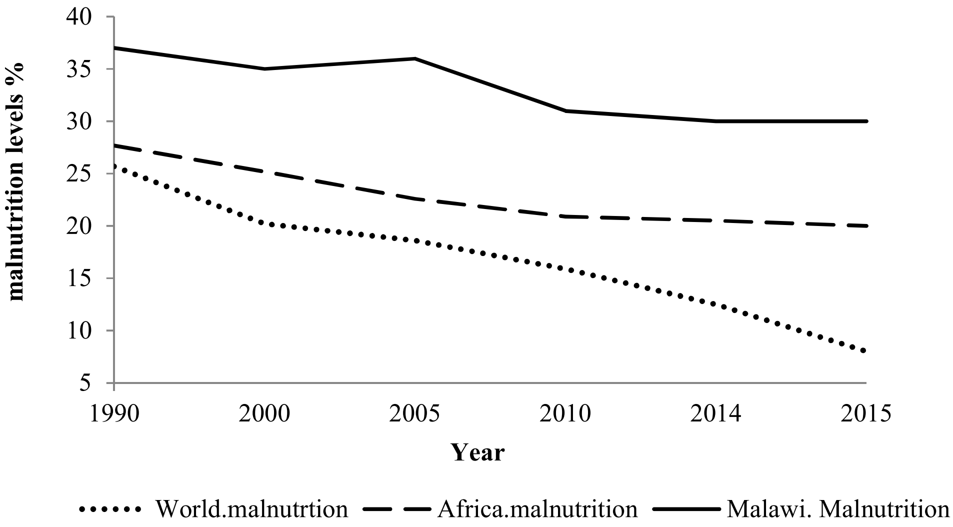


Figure 3:2. The status of global, Africa and Malawi malnutrition trends
Source (FAO *et al.* 2015)

3.2.5 Emergence of food governance

Food governance systems may be broadly classified into two or three types, which include the "production or dependent", the "self-sufficient" and the "sovereign" food systems (Pinstrup-Andersen 2009). The global primary premise on food governance, has been the "production approach", which assumes that countries and regions with high comparative advantage would produce and supply enough food to countries that are unable to meet own requirements (Mechlem 2004). This approach focuses on attaining food security at global level and assumes that all countries and communities have enough trade entitlements to access food, a situation which is not reflected in most developing countries. Even for rich importing countries, the volatile food prices and control of market systems by producing countries pose a considerable risk to this approach (McMichael 2005). The "food self sufficiency" aims at producing enough food within a particular region or country. Even though there could be enough production to potentially meet minimum physical food requirements, the concept falls short in guaranteeing minimum consumption within the region or country where is it produced, as it gives leeway to business enterprises to export food whilst leaving the local consumers hungry. In this way self-sufficient is similar to the dependent system. Sen, (1981) notes that such governance system tend to handle food as a purely "capitalistic" rather than a "human rights" issue.

Recently the "food sovereignty" governance system touted as morally ethical and possessing a human right dimension to food, has come into prominence (Rosset 2008; Wittman *et al.* 2010). It is argued as a potential solution to attainment of food security and poverty eradication among poor resource families (Desmarais 2003). As a concept, food sovereignty priorities and reserves resources to produce enough culturally accepted food before production of cash crops and guarantees minimum consumption for each small region, before food exports (Pimbert 2009). To minimize the cost of trade and ensure greater access within a country, food sovereignty advocates for producers' geographical closeness to the consumers (Pimbert 2009). Utilisation of land by big estates for non-food crops like biofuels or distribution of genetically modified foods against the culture and preference of deficit communities is objectionable (Pimbert 2009). Views against this approach point to the fact that it negates the principle of comparative advantage and that the interests of producers when restricted to a particular region may not always agree with consumer needs.

3.2.6 Previous studies on food security

Most studies that have analysed food security, have adopted a capitalistic or the dependent system than a sovereign or human rights based perspective to find ways under which hunger may be eradicated for smallholder farmers. Many studies assume that food produced in one region can be accessed anywhere (Arndt *et al.* 2012; Leclère *et al.* 2013). This is often not the case with poor smallholder farmers. There has also been a tendency to focus on single objective of maximizing income (Klein *et al.* 2013; Strauss *et al.* 2012). This approach may be inapplicable for smallholder farmers, who mostly seek food sufficiency before income maximisation.

Literature contains many scientific studies that exclude technologies which are routinely used by smallholder farmers, like conservation agriculture and *Falbedia albida* (Akpalu *et al.* 2008; Klein *et al.* 2013). Despite, the general consensus for urgent policy interventions to increase productivity of smallholder farmers in order to eradicate hunger (Moyo *et al.* 2015), not many studies have attempted to analyse and offer policy recommendations on land use options levels. The focus of this chapter is therefore to fill the highlighted gaps in understanding the effect of alternative food governance systems on land use and hunger eradication among smallholder farmers in Malawi.

3.3 Research questions

3.3.1 Is there a significant difference between different food governance systems' effect on hunger eradication among smallholder farmers in Malawi?

3.3.2 What level of subsidy or market support is required to eradicate hunger among smallholder farmers in Malawi?

3.3.3 What are the optimal land use options to eradicate hunger among smallholder farmers in Malawi?

3.4 Methods

3.4.1 Data sources and model adjustment

Biophysical and economic data was sourced from MASM in Chapter two. To analyse the stated objective MASM is adopted with five adjustments as follows: Firstly, the studied period was restricted to 2010, which is the base year of the model. Secondly, instead of 1300 HRUs regions in Malawi, crop yields were only simulated on 924 effective HRU regions. This was done to consider the HRU regions where crop production was practically possible, leaving out HRUs under rock outcrops or plonosols and protected areas like parks and game reserves. Thirdly, the minimum food restrictions (**see Chapter 2, section 2.4.9.3.6, eq 2.11**) was activated under sovereign and deactivated under dependent governance system. Fourthly, the benefit or cost of environmental degradation which is estimated as a product of soil organic carbon sequestered and its market price ($/ton soc) i.e. $\sum_{t,r}(\zeta_{t,r} \, . \; C_{t,r})$ was deactivated. Lastly, as there was only one year for analysis, the benefit of outstanding storage ($p_{j,t,r} \, . S_{j,t,r}$) and the cost of storage, ($\varsigma_{j,t,r} \; . S_{j,t,r}$) had values of zero.

3.4.2 Model scenarios

The model scenarios constitute food governance system, policy intervention type and intervention level. The decision to produce a particular crop and level of production in a particular region is dependent upon the farmer group, governance type, intervention type and technology type (**Figure 3:3**). For application of interventions, farmers are categorized into two groups, the poor and the non-poor. The poor and the non-poor are assumed as those who lived below and above the poverty line in 2010 i.e. 1.25$/day. On this basis, the non-poor farmers are not necessarily rich. Three governance systems are analysed which include the business as usual (BAU), the dependent and the sovereign governance systems. The BAU governance depicts no deviation from historical crop area and technology levels. Unlike the BAU, the dependent and sovereign governance systems analysed the optimal crop area and technology levels within available resources. While both farmer groups benefited from market support only poor farmers received subsidy support.

Four intervention types considered in the analysis included no intervention, subsidy, market and interaction of subsidy and markets. The no intervention depicts a situation where farmers have no support from public policy. The subsidy intervention is justified by the prevailing poverty rates as 40% of the population, mostly smallholder farmers live below poverty line. The Malawi government has since 2005 undertaken a targeted Farm Input Subsidy Programme (FISP), where poor farmers are subsidized with farm inputs to increase maize and at times tobacco productivity. Dorward *et al.* (2008) estimated that subsidy support in Malawi ranged between 50% and 70% of fertilizer costs. The study used three subsidy intervention levels of 50% (S1), 60% (S2) and 70% (S3) of actual market price for fertilizer. In addition to tobacco and maize, all selected crops were eligible for subsidy intervention.

For this chapter, markets were generally categorised as local and external markets. The local markets offer lower prices when compared to external markets, which are mainly influenced by regional demand differences. A combination of factors that include transport and appropriate storage infrastructure restrict smallholder farmers from accessing external markets. The external markets are therefore mainly accessed by the middlemen, who are known to take advantage of smallholder farmers. Middlemen usually buy produce at lower prices, even far less than the production costs and pass the produce into the value chain at higher prices. The market intervention is therefore designed as a policy measure to give farmers the opportunity to access better markets. Each market intervention level depicts a displacement factor of the middleman in the external markets. In this way the role of the middlemen is gradually reduced and the benefits of accessing the external markets are gradually retained by smallholder farmers. The adjustment factor or market intervention levels are deduced from price differences between the external and local markets. Observed data had average prices difference of 30%. To displace middlemen from external markets the price differences were theoretically reduced to 20% (M1), 10% (M2) and 0% (M3), where 0% (M3) adjustment level represents total displacement of the middleman. The last intervention is called the interaction intervention, where subsidy and market interventions interacted simultaneously. This is usually the case as no single policy is implemented in isolation. Theoretical combinations of interactions were decided as minimum (S1+M1), medium (S2+M2) and maximum (S3+M3) interaction.

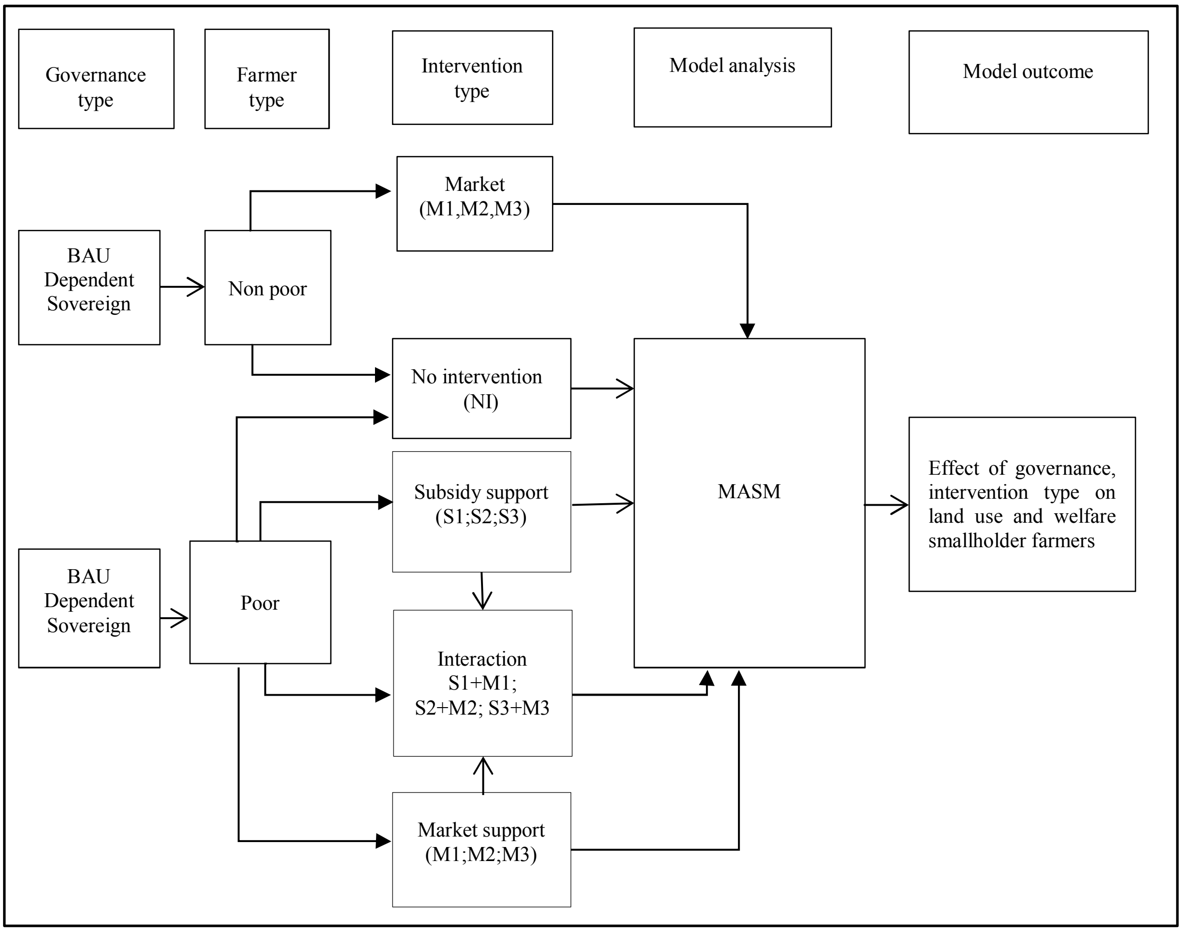


Figure 3:3. Diagrammatic outline of food governance scenarios

Interaction levels between subsidies and markets: Minimum = (S1+M1), Medium = (S2+M2), Maximum = (S3+M3), NI = No intervention, S1,S2,S3 = subsidy support levels in % of fertiliser prices, M1,M2,M3 = market support levels where middleman losses market access.

3.4.3 Theoretical review of expected scenario effect

3.4.3.1 Effect of food governance and no intervention

The BAU and dependent governance system have similar diagrammatic response to welfare under no intervention (**Figure 3:4-a**). Though not shown here, the two systems have different equilibrium points and therefore different land use options and welfare outputs. The BAU land use options are not affected by intervention type since its crop mix is already fixed from observed land use levels in 2010. With the sovereign governance (**Figure 3:4-b**), the model forces minimum local food production and consumption (Q^R). If a particular region is able to produce the minimum food requirement, then (Q^R) will occur to the left of the equilibrium point i.e. (Q^{R1}) (**Figure 3:4-b**). Otherwise if a particular region fails to produce the minimum food requirement then (Q^R) occurs to the right of the equilibrium point, (Q^{R2}) (**Figure 3:4-b**). When there is insufficient food production (Q^{R2}) under sovereignty, the model will priorities resources i.e. land to food production until the additional food requirement (*dQ*) is attained. Under sovereignty governance, non-food crops can only be produced after attaining minimum food production, and food products can only be exported after attaining minimum food consumption.

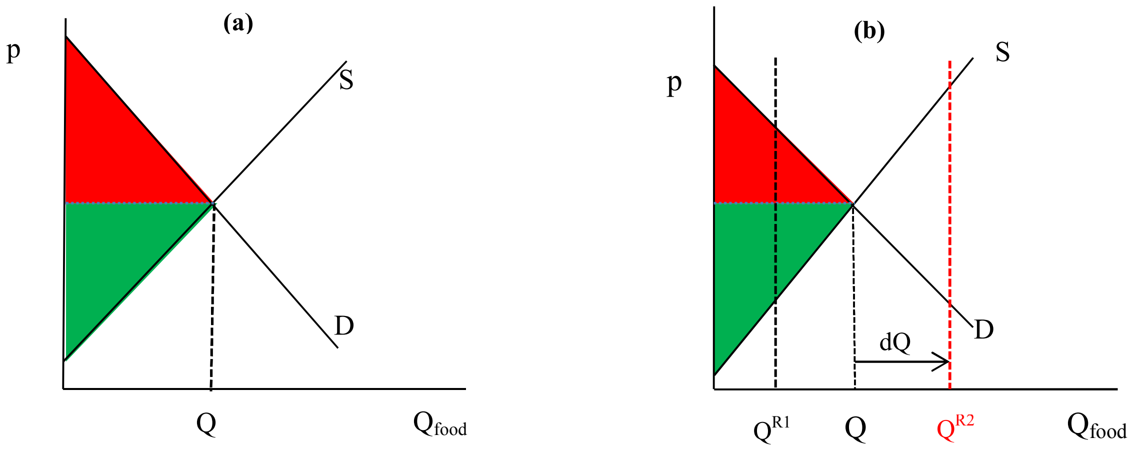


Figure 3:4. Effect of food governance and no intervention on welfare
Red area = consumer surplus, green area = producer surplus, S and D = national supply and demand.
Q^{R1} and Q^{R2} = Minimum food requirement occurring before and after equilibrium point. (a) = BAU or dependent which is not restricted with food requirements. (b) = Sovereign governance with restrictions on minimum food requirements

3.4.3.2 Effect of food governance and market support

Figure 3:5-b represents a situation when middlemen take control of external markets without smallholder farmers themselves participating. In this case smallholder farmers do not receive the full external market price as a premium is paid to the middleman. In **Figure 3:5-c** the middlemen are displaced from market participation. In this case, local producers (smallholder farmers) gain while the middlemen lose (in relation to **Figure 3:5-b**) and local consumers also lose (in relation to **Figure 3:5-a**). **Figure 3:5-d** portrays the effect of sovereign food governance. Sovereign governance reduces exports and therefore local consumers have access to more food (in relation **to Figure 3:5-c**). The cost of additional food resulting from sovereign food governance restrictions may be paid by the government or would simply be counted as a loss to producers as they are prevented from accessing better markets.

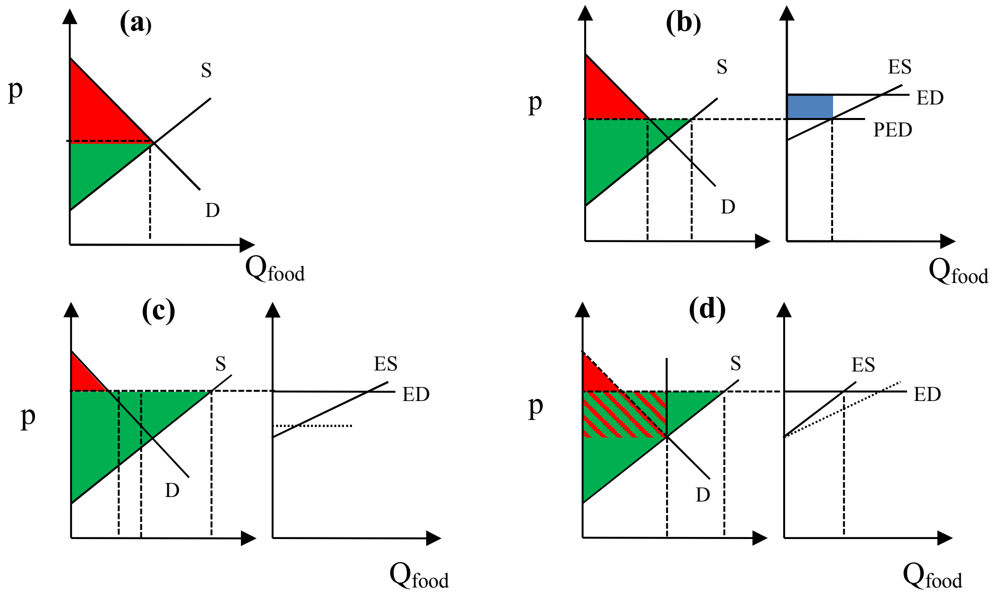


Figure 3:5. .Effect of food governance and market support to welfare
Red area = consumer surplus, green area = producer surplus, blue area = middlemen surplus. S and D = national supply and demand functions. (a) = autarky (no trade), b = smallholder farmers access external markets through middlemen, c = smallholder farmers access external markets directly (middlemen displaced), d = sovereign governance system restrictions applied.

The middlemen welfare (M), is gradually reduced with each market intervention level (z) to zero. The middlemen welfare is estimated as the price differences in external market ($p_{j,t,\tilde{r}}$) and local market ($p_{j,t,r}$) multiplied by consumption level in external market ($Q_{j,t,\tilde{r}}$) (**eq. 3:1**).

$$M = \sum_{j,t,r} \left(\mathrm{p}_{j,t,\tilde{r}} - \mathrm{p}_{j,t,r} \right) . Q_{j,t,\tilde{r}} \qquad \textbf{(eq. 3:1)}$$

The Malawi government pays for the subsidy cost ($S_{t,z}$) as in **(eq. 3:2)** which are estimated as product of farm input unit cost i.e. fertiliser price per hactare ($\Phi_{b,z}$), and crop variable under poor farmers ($L_{\text{"poor-farmer"},r,t,j,m}$)

$$S_{t,z} = \sum_{b,r,j,m} (\Phi_{b,z}) \; . L_{\text{"poor-farmer"},r,t,j,m} \qquad \forall_{t,z} \qquad \textbf{(eq. 3:2)}$$

3.4.3.3 Consumer welfare estimation

The original objective function (**see chapter 2, (eq. 2:**3) is revised to reflect model changes in this chapter. The new consumer welfare (W) (**eq. 3:3**) is the product of consumption ($Q_{j,\text{"2010"},r}$) and market prices ($p_{j,\text{"2010"},r}$), summed over all crop products (*j*) and regions (*r*) minus the costs of production ($\text{ç}_{j,m,\text{"2010"},r} \; . L_{j,m,\text{"2010"},r}$) and costs of trade ($\text{ƫ}_{j,r,\tilde{r}} \; . T_{j,\text{"2010"},r,\tilde{r}}$).

$$W = \begin{pmatrix} \sum_{j,r} \left[\int \; p_{j,\text{"2010"},r} \left(Q_{j,\text{"2010"},r} \right) dQ_{j,\text{"2010"},r} \right] \\ \sum_{j,m,r} \left(\text{ç}_{j,m,\text{"2010"},r} \cdot L_{j,m,\text{"2010"},r} \right) \\ - \sum_{j,r} \left(\text{ƫ}_{j,r,\tilde{r}} \; . T_{j,\text{"2010"},r,\tilde{r}} \right) \end{pmatrix} \qquad \textbf{(eq. 3:3)}$$

3.4.3.4 Producer revenue

Producer revenue was estimated as a product of price ($p^{*}_{j,\text{"2010"},r}$) and quantity demanded ($Q^{*}_{j,\text{"2010"},r}$) at equilibrium point as in (**eq. 3:4**):

$$R = \sum_{j,r} \left(p^*_{j,"2010",r} \cdot Q^*_{j,"2010",r} \right) \qquad \textbf{(eq. 3:4)}$$

3.4.3.5 Food consumption index

Relative changes in food consumption were estimated using quantity based Fisher and Hunger indexes. Firstly different food baskets or actual food consumption and respective prices are estimated for governance (d), intervention type (z) and intervention level (s). The status quo i.e. the BAU represents the food quantity (Q_d) and food price (p_d). Changes in governance and intervention type results into new food quantities ($Q_{(d+1)}$) and new food prices ($p_{(d+1)}$). The Fischer index (I_F) in **(eq. 3:5)** is estimated as geometric mean of the Laspeyres index (I_L) which uses base baskets: $I_L = \left(\frac{p_d \cdot Q_{(d+1)}}{p_d \cdot Q_d} \right)$ and Paashe indexes (I_P) which uses current baskets: $I_P = \left(\frac{p_{(d+1)} \cdot Q_{(d+1)}}{p_{(d+1)} \cdot Q_d} \right)$:

$$I_F = (I_L \,. I_P \,)^{1/2} \qquad \textbf{(eq. 3:5)}$$

Hunger index (H_r) portray the state of hunger for each governance, intervention type and level group type. The hunger index **(eq. 3:6)** is estimated by converting the food baskets into calories ($k_e \cdot Q_{(d+1)}$) divided by the minimum calorie food requirements for each region ($365\varphi \,.\, \Psi_{t,r}$), (**see Chapter 2, (eq. 2:10**). A Hunger index of greater than one represents eradication of hunger where as an index less than 1 represents persistence of hunger:

$$H_r = {(k_e \cdot Q_{(d+1)})}\big/{(365\varphi \,.\, \Psi_r)} \qquad \forall_{d,r} \qquad \textbf{(eq. 3:6)}$$

3.5 Results

The results for this chapter are presented in terms of land use options, welfare impacts, food consumption indexes and implications of each governance choice and intervention level.

3.5.1 Crop mix

Table 3:1 presents results on the effect of governance and intervention level on crop mix outcomes. In order to have a fixed basis for comparison, cultivated areas are presented as proportion to total arable land. Food governance system had no significant difference on crop areas whereas intervention type had a significant difference to total cultivated areas at $p=0.05$ (Appendix 1). Maize was the dominant crop in all scenarios and contributed between 33% and 62% of total available land. Subsidy resulted into reduced crop areas, this as observed later was due to farmers shifting to high productive technologies which require less crop areas. Market intervention on the other hand motivated farmers to increase cultivated areas. The results also showed increase in food crop areas under sovereign than dependent, which is the result of model design to prioritise promotion of food crops under sovereign systems.

Table 3:1. Effect of food governance on crop areas

Governance type	Intervention type	Crop choice (% of total arable land)										Total grown area (1000Ha)
		cassava	cotton	groundnut	maize	Paprika	rice	sorghum	soybean	sugarcane	tobacco	
BAU	NI	3.66	1.42	4.31	44.91	0.07	0.80	2.30	2.90	0.37	2.58	2811.268
Dependent	NI	3.96	1.67	4.32	44.74	0.08	0.94	2.36	2.55	0.52	3.11	2851.931
	S1	3.05	1.49	3.50	35.07	0.08	0.90	1.72	1.81	0.42	2.32	2236.282
	S2	2.69	1.31	3.09	31.08	0.08	0.76	1.57	1.52	0.48	2.33	1993.005
	S3	2.80	0.88	3.21	29.62	0.06	0.78	1.44	1.73	0.37	2.18	1911.151
	M1	4.60	1.99	6.19	61.50	0.11	1.18	3.32	3.08	0.71	4.63	3876.763
	M2	4.69	2.12	6.26	61.29	0.14	1.23	3.31	3.52	0.74	4.52	3899.639
	M3	4.83	2.27	6.31	61.92	0.12	1.29	3.46	3.86	0.74	4.24	3953.499
	MN	4.60	1.99	6.19	61.5	0.11	1.18	3.32	3.08	0.71	4.63	3876.762
	MD	4.69	2.12	6.26	61.29	0.14	1.23	3.31	3.52	0.74	4.52	3899.639
	MX	4.83	2.27	6.31	61.92	0.12	1.29	3.46	3.86	0.74	4.24	3953.499
Sovereign	NI	4.67	1.87	5.80	59.90	0.11	1.10	3.19	3.42	0.57	3.96	3755.768
	S1	2.77	1.33	3.39	33.02	0.08	0.80	1.60	1.83	0.39	2.29	2108.025
	S2	2.83	1.24	3.33	32.76	0.08	0.79	1.81	1.67	0.37	2.48	2102.201
	S3	3.10	1.08	3.27	32.86	0.06	0.75	1.74	1.81	0.40	2.26	2100.746
	M1	4.77	1.99	6.20	61.69	0.11	1.19	3.32	3.09	0.71	4.64	3894.918
	M2	4.83	2.12	6.27	61.43	0.14	1.24	3.31	3.52	0.74	4.53	3912.828
	M3	4.99	2.28	6.32	62.31	0.12	1.3	3.47	3.90	0.74	4.24	3981.412
	MN	4.77	1.99	6.20	61.71	0.11	1.19	3.32	3.12	0.71	4.59	3894.725
	MD	4.84	2.12	6.28	61.43	0.14	1.24	3.29	3.52	0.74	4.55	3914.151
	MX	4.99	2.28	6.32	62.31	0.12	1.30	3.47	3.90	0.74	4.24	3981.409

p-levels = 0.05: *governance = no significant different ; intervention level = significantly different*

NI = No intervention, S1,S2,S3 = subsidy support levels in % of fertiliser prices, M1,M2,M3 = market support levels where middleman losses market access. Interaction levels between subsidies and markets: MN = (S1+M1), MD = (S2+M2), MX= (S3+M3).

3.5.2 Technology mix

Technology mixes are presented in **Table 3:2**. Under no intervention, changing from BAU to one of the other two governance systems resulted in reduced adoption of subsistence farming from 38.19% to 6.86.9% (dependent) and 44.16% to 6.73% (sovereign) of total cultivated areas. Instead, subsistence farming was replaced by more productive technologies like conservation agriculture and *Falbedia albida*, which in total contributed up to over 20% under (dependent; M1) and 15% under (sovereign; M1) systems. The highest changes in technology choices were observed under intensive farming from 2.9% under (BAU; NI) to 73% under (sovereign; MX). While other technologies have one harvest per season, intensive technology i.e. irrigation may have two harvest in a season. This means that the actual crop areas under intensive farming may range between 37% and 73% of the cultivated area.

Table 3:2. Effect of food governance on technology adoption

Governance type	Intervention type	Technology mix (% of total arable area)					Total cultivated area (1000 Ha)
		Conservation agriculture	Falbedia albida	Intensive farming	Optimal fertilisation	Subsistence farming	
BAU	NI	0.31	0.31	2.69	21.8	38.19	2811.268
	NI	17.78	14.79	1.67	8.40	21.57	2851.931
	S1	5.71	1.76	8.00	13.54	21.35	2236.282
	S2	5.30	1.26	8.90	12.14	17.28	1993.005
	S3	5.57	1.99	9.80	8.87	16.81	1911.151
	M1	18.34	4.79	16.68	8.45	39.02	3876.763
	M2	10.32	1.17	58.71	2.36	15.24	3899.639
	M3	4.11	1.23	73.44	3.37	6.86	3953.499
	MN	15.7	3.25	17.83	6.35	44.16	3876.762
	MD	7.93	0.60	58.27	6.46	14.53	3899.639
Dependent	MX	2.84	0.59	72.92	5.03	7.63	3953.499
	NI	13.62	17.66	1.19	6.26	45.82	3755.768
	S1	3.67	1.66	9.41	16.74	15.98	2108.025
	S2	5.21	1.55	9.51	14.94	16.13	2102.201
	S3	5.75	1.50	9.83	11.90	18.33	2100.746
	M1	12.34	3.98	17.69	9.98	43.69	3894.918
	M2	9.50	1.84	58.75	4.50	13.5	3912.828
	M3	4.34	0.72	73.95	3.90	6.73	3981.412
	MN	15.28	3.83	18.33	9.15	41.1	3894.725
	MD	8.70	1.23	58.61	7.14	12.45	3914.151
Sovereign	MX	2.75	0.58	73.08	5.56	7.67	3981.409

p-levels = 0.05: *governance = no significant different ; intervention level =significantly different*

NI = No intervention, S1,S2,S3 = subsidy support levels in % of fertiliser prices, M1,M2,M3 = market support levels where middleman losses market access. Interaction levels between subsidies and markets: MN = (S1+M1), MD = (S2+M2), MX = (S3+M3).

3.5.3 Welfare effects

The effect of food governance and intervention level on welfare is presented in **Table 3:3**. Both governance choice and intervention type had significant effect on welfare outcome at $p = 0.05$ (Appendix 2). Producer revenues were highest under dependent governance than under sovereign governance. However, Malawian consumers and middlemen had highest welfare increase under sovereign when compared to dependent system. In comparison, governance systems had no significant influence on cultivated areas and technology choice levels. However on welfare the governance systems are significantly different. This means that the food governance becomes an important factor in guaranteeing minimum food consumption by controlling food exports rather than the influence it has on crop and technology

Table 3:3. Effect of food governance on welfare outcomes

Governance type	Intervention type	Welfare type and welfare change (Δ %)		
		Consumer welfare	Middleman welfare	Producer revenue
BAU	NI	0.00	0.00	0.00
Dependent	NI	0.02	-3.14	-2.13
	S1	0.02	0.85	1.27
	S2	-0.01	1.99	1.97
	S3	0.02	2.15	2.11
	M1	0.49	41.88	69.47
	M2	0.93	54.07	205.31
	M3	1.32	-100.00	235.78
	MN	0.49	41.88	69.47
	MD	0.93	54.07	205.31
	MX	1.32	-100.00	235.78
Sovereign	NI	1.89	1.94	-3.75
	S1	1.89	4.33	-1.52
	S2	1.90	4.67	-1.26
	S3	1.90	3.53	-1.99
	M1	2.12	43.46	66.52
	M2	2.32	54.76	202.83
	M3	2.52	-100.00	234.05
	MN	2.12	43.46	66.52
	MD	2.35	54.77	202.88
	MX	2.52	-100.00	234.05

***p-levels = 0.05: both** governance and intervention level = significantly different*

NI = No intervention, S1,S2,S3 = subsidy support levels in % of fertiliser prices, M1,M2,M3 = market support levels where middleman losses market access. Interaction levels between subsidies and markets: MN = (S1+M1), MD = (S2+M2), MX = (S3+M3).

3.5.4 Food consumption indexes

Table 3:4 presents the results on food consumption changes and hunger indexes. Governance choice and intervention type were both found to significantly affect consumption levels (Appendix 3). All the indexes portray higher consumption under sovereign than dependent food systems. The results show that hunger would be eradicated only with dependent system (M3) while was easily eradicated under sovereign systems with all intervention levels. This shows that higher producer revenues under dependent systems do not necessarily translate into better food access.

Table 3:4. Effect of food governance on food consumption levels

Governance type	Intervention type	Consumption (Giga calories)		Fischer index	Hunger Index	Hunger status
		Minimum required c	Actual consumption			
BAU	NI	10177.73	9529.686	1.00	0.94	✘
Dependent	NI	10177.73	9536.15	1.01	0.94	✘
	S1	10177.73	9536.151	1.01	0.94	✘
	S2	10177.73	9529.064	1.00	0.94	✘
	S3	10177.73	9536.151	1.01	0.94	✘
	M1	10177.73	9775.547	1.03	0.97	✘
	M2	10177.73	10018.93	1.06	0.99	✘
	M3	10177.73	10270.37	1.08	1.01	✓
	MN	10177.73	9775.562	1.03	0.97	✘
	MD	10177.73	10018.94	1.06	0.99	✘
	MX	10177.73	10270.37	1.08	1.01	✓
Sovereign	NI	10177.73	11042.34	1.16	1.09	✓
	S1	10177.73	11042.34	1.16	1.09	✓
	S2	10177.73	11049.43	1.16	1.09	✓
	S3	10177.73	11049.43	1.16	1.09	✓
	M1	10177.73	11116.88	1.17	1.10	✓
	M2	10177.73	11219.41	1.18	1.11	✓
	M3	10177.73	11309.82	1.19	1.12	✓
	MN	10177.73	11116.88	1.17	1.10	✓
	MD	10177.73	11233.06	1.18	1.11	✓
	MX	10177.73	11309.82	1.19	1.12	✓

p-levels = 0.05: *both governance and intervention level = significantly different*

Hunger eradication status: ✘ = not eradicated, ✓ =eradicated. NI = No intervention, S1,S2,S3 = subsidy support levels in % of fertiliser prices, M1,M2,M3 = market support levels where middleman losses market access. Interaction levels between subsidies and markets: MN = (S1+M1), MD = (S2+M2), MX = (S3+M3).

3.5.5 Implication of governance choice

External factor consideration is important to properly advice decision making. In the following section, an analysis of governance choice and its related effect on cost of subsidies and implications on land use ratio (LUR) are considered as shown in **Table 3:5**. The subsidy costs is presented in relation to the Malawi national budget of 2010 while the LUR denotes the ratio of crop area used to total available arable land.

As Malawi is one of the poorest countries cost effectiveness may be more important than seeking highest welfare outputs. Similarly, as most smallholder farmers have low land sizes highest LUR might result to high soil degradation levels. Policy decision must seek compromise between maximising hunger eradication in consideration of costs and probable environmental effects. The results show varied LURs between governance choice and intervention level. In general, the options that led to highest hunger eradication like (sovereign; S3), and (sovereign; MX) had the highest LURs and cost of subsidies. However the combination of sovereign systems and market support, which also managed to eradicate hunger, had zero subsidy costs. This suggests that sovereign and market intervention may offer optimal options to eradicate hunger among smallholder farmers.

Table 3:5. Effect of food governance on land use and subsidy costs

Governance type	Intervention type	Hunger index (H)	Feasibility	LUR	Subsidy cost (% national budget)
BAU	NI	0.94	✘	63.28	0.00
	NI	0.94	✘	64.20	0.00
	S1	0.94	✘	50.34	8.81
	S2	0.94	✘	44.86	9.30
	S3	0.94	✘	43.02	9.40
	M1	0.97	✘	87.26	0.00
	M2	0.99	✘	87.78	0.00
	M3	1.01	✓	88.99	0.00
	MN	0.97	✘	87.26	11.23
	MD	0.99	✘	87.78	20.80
Dependent	MX	1.01	✓	88.99	28.16
	NI	1.09	✓	84.54	0.00
	S1	1.09	✓	47.45	8.20
	S2	1.09	✓	47.32	10.94
	S3	1.09	✓	47.29	11.47
	M1	1.10	✓	87.67	0.00
	M2	1.11	✓	88.08	0.00
	M3	1.12	✓	89.62	0.00
	MN	1.10	✓	87.67	13.91
	MD	1.11	✓	88.11	22.11
Sovereign	MX	1.12	✓	89.62	29.04

p-levels = 0.05: *both governance and intervention level = significantly different*

✓ = feasible option to eradicate hunger ✘ = not feasible option to eradicate hunger. NI = No intervention, S1,S2,S3 = subsidy support levels in % of fertiliser prices, M1,M2,M3 = market support levels where middleman losses market access. Interaction levels between subsidies and markets: MN= (S1+M1), MD = (S2+M2), MX = (S3+M3).

3.6 Discussion

In this chapter the effect of different food governance, intervention type and level on hunger among smallholder farmers in Malawi were analysed. The following section discusses the results on optimal crop and technology mix; land use ratio; welfare and food consumption indexes.

Maize remained the dominant crop under all food governance systems and intervention. This is due to the crop mix restrictions in the model (**eq. 2:6**). Historical data show that maize is grown on more than 44% of total arable land and contributed 75% to total food consumption (GoM 2012a). While there may be acceptable food substitutes, smallholder farmers show a clear preference for maize (Smale *et al.* 1995). Cultural preference has often proved a challenge in eradicating hunger as alternative more resilient crops are usually not preferred by farmers (Minot 2010). Besides maize there was more land allocated to food crops like cassava, rice and sorghum under sovereign than dependent food systems. This reflects the model design where food crops are given priority in the sovereign systems. Market support resulted into higher crop areas than subsidy support. This is obvious in that input subsidies reduce crop production costs but don't necessarily increase crop prices and that farmers after getting subsidies choose more productive technologies that require less land to produce.

Technology adoption rates for conservation agriculture and *Falbedia albida* increased from observed levels of 0.31% to around 20% for conservation agriculture and 0.31 % to 8% for *Falbedia albida*. These adoption rates are high when compared to southern Africa average of 3% (Milder *et al.* 2011). In practice, farmers face challenges like shortage of seedlings and survival of trees for *Falbedia albida* or the competing needs on crop stocks for soils cover under conservation agriculture (Mfune 2014). It is also advisable to increase area under intensive farming i.e. irrigation infrastructure. The optimal levels lie between 2.69% to 36% depending on governance and intervention type. This would require increasing the area equipped with irrigation infrastructure from currently 110,000 hectares to 990,000 hectares. The government through the Greenbelt initiative set a policy target to construct 2 million hectares under irrigation infrastructure (GoM 2011a). Compared to this analysis, the Greenbelt initiative targets may be too high to be economically inefficient. Both findings of the study and government policy are outside total amount of 650,000 hectares which is estimated to be easily irrigable under gravity fed irrigation (Ferguson & Mulwafu 2005). This then would require more investments other than flood irrigation to deliver water to crop areas. However the study finding on irrigation area might be too high since the study considered only one base year 2010, which as will be noted later in Chapter 4, did not have favourable biophysical condition which resulted into low crop yields and therefore required higher investments in irrigation infrastructure. If the analysis had included more years, the optimal cultivated area under irrigation would have been lower.

The land use ratios (LUR) ranged from 43% under (dependent system; S3) to 89% under (sovereign; M3). Unlike with the findings of Chibwana *et al.* (2012), who reported that subsidies lead to allocation of 45% more land under maize. The model results show that maize was dominant crop, but subsidies reduced its dominance i.e. from 44% under (BAU; NI) to 29% under (dependent; S3) and 32% of total arable land under (sovereign; S3).The difference is that Chibwana *et al.* (2012), analysed subsidies only when applied to maize and therefore farmers were motivated to choose maize over other crops. In the model all crops had chance of being subsidies depending on the crop area levels. However, in part, the results agree with Chibwana *et al.* (2012) in that the application of subsidies did not lead to increased total crop areas. The model results show a decrease in crop areas of 33% i.e. from 2,850 thousand hectares under (BAU; NI) to 1,911 thousand hectares under (dependent; NI) and a decrease of 24% i.e. to 2,108 thousand hectares under (sovereign; NI). The decrease is explained in that subsidies influence farmers to adopt high yielding technologies which require reduced crop areas. Market interventions of the other hand increased crop areas for all crops. The highest simulated land use ratio was 89% (sovereign; MX). Such high land use ratios create challenges for farmers, as it becomes more difficult to practice fallow in order to improve soil conditions. Otherwise, the cost of supporting farmers should not be limited to the costs of interventions only, but include the cost of land degradation to better reflect its impact on social welfare.

While availability of land at household level has been suggested to be one of the causes of hunger among smallholders farmers (Holden *et al.* 2006). The situation is different at national level. The fact that the highest LUR levels were below 100% i.e. 89%, suggest that food security can be achieved even with the limited available land resources among smallholder farmers. As noted by Myers (1999), the average minimum land required per person to meet basic livelihood status is about 0.07 hectares. In 2010, the average, a minimum arable land holding sizes was 0.28 hectares per person (GoM 2012a), which theoretically is enough land to provide for basic needs. With increased adoption rates of high productive technologies like intensive farming, average land holding sizes, which are estimated to decrease to 0.25 hectares per person by year the 2050 due to population growth, would still be adequate to provide minimum food requirements for smallholder farmers. This deduction however applies to the national level, as such regional prioritized land distribution, particularly to households with little land in certain EPAs, would be necessary for particular households.

The dependent system achieved higher producer revenues than sovereign system; however the sovereign system had higher consumer welfare than the dependent systems. This is obvious in that the dependent system seeks for economic efficiency for producers whereas the sovereign protects the rights of consumers. The market intervention increased producer revenue but had negative effect of consumer welfare and the middleman welfare. Consumer welfare decreased due to higher prices that smallholder farmers accessed in the external market. Access to external markets displaced the role of middlemen and their welfare reduced to zero (i.e. -100%) when smallholder farmers had full access to markets. Displacing middlemen may be possible if the farmers form associations and negotiate on prices and contracts in advance. Otherwise small production levels of farmers at individual level makes them prone to middlemen dominating the markets.

Sovereign governance emerged the most effective system to eradicate hunger. The main reasons for this are twofold. Firstly, assigning smallholder farmers to produce enough food to meet the minimum caloric requirements of their region reduces food costs that may arise due to transportation from other long distance regions. Sovereignty would therefore in effect reduce the food distribution problems that exist in many regions. The second reason is the restrictions on food export when a particular region fails to attain a minimum food production requirement. From the results, the analysis of variance showed that the sovereign governance was more effective due to restriction on food trade, other than restriction on food crop areas. This is practically evident in Malawi, where in some years the total production is sufficient to meet minimum food requirements and yet food is exported away leaving the local communities hungry. At worst, the government even buys food from outside Malawi at much higher prices to carter food shortage crisis periods

As already discussed highest outputs are costly and may have negative implications on land use. As reported by Dorward & Chirwa (2011), subsidy costs in Malawi amounted to 16% of the national budget and 70% of the budget of the Ministry of Agriculture in 2010. This is argued to suffocate other equally important developmental sectors, like health and education. The highest subsidy costs were noted under (sovereign; MX) at 29% of the national budget, which also resulted in highest land use ratios. The cheaper options that satisfy minimum policy targets for basic welfare appear under sovereign and market combinations.

3.7 Conclusions

In this chapter, alternative food governance and intervention options to eradicate hunger among resource poor smallholder farmers in Malawi were analysed. The study has filled gaps related to food governance, hunger eradication and land use. The dependent food system improves farmer producer revenue more than the sovereign food system. However the sovereign food governance system, which prioritises the production of regional minimum calorie requirements over income maximization, is most effective in eradicating hunger. Additional intervention in form of subsidies and marketing support increases the producer revenues, but market support has better effect on hunger eradication than subsidies. While the actual crop, technology choices depend on cost of technology and implication on land use this chapter concludes that the combination of sovereign food governance system and markets interventions provide the most feasible options to improve welfare and eradicate hunger among smallholder farmers in Malawi.

3.8 Appendixes

Appendix 3:1. Analysis of variance on food governance, intervention type and land use

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Dependent	10	730.4	73.0	404.0
Sovereign	10	757.3	75.7	385.5
NI	2	148.7	74.3	206.9
S1	2	97.7	48.8	4.16
S2	2	92.1	46.0	3.02
S3	2	90.3	45.1	9.10
M1	2	174.9	87.4	0.08
M2	2	175.8	87.9	0.04
M3	2	178.6	89.3	0.19
MN	2	174.9	87.4	0.08
MD	2	175.8	87.9	0.053
MX	2	178.6	89.3	0.19

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	36.11	1	36.11	1.73	0.22	5.117
Columns	6918.4	9	768.71	36.84	4.86E-06	3.178
Error	187.77	9	20.86			
Total	7142.30	19				

Appendix 3:2. Analysis of variance on food governance, intervention type and consumer welfare

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
dependent	10	20.73	2.073	0.00012
sovereign	10	21.06	2.106	2.82E-05
NI	2	4.162	2.081	0.000739
S1	2	4.162	2.081	0.000739
S2	2	4.162	2.081	0.000768
S3	2	4.163	2.081	0.000753
M1	2	4.177	2.088	0.000562
M2	2	4.190	2.095	0.000409
M3	2	4.202	2.101	0.000304
MN	2	4.177	2.088	0.000562
MD	2	4.190	2.095	0.000428
MX	2	4.202	2.101	0.000304

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0054	1	0.0054	319.88	2.43E-08	5.11
Columns	0.0012	9	0.00013	7.970	0.0024	3.17
Error	0.00015	9	1.69E-05			
Total	0.0067	19				

Appendix 3:3 . Analysis of variance on food governance, intervention type and Hunger Index

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
dependent	10	9.65	0.96	0.0008
sovereign	10	10.95	1.09	0.0001
NI	2	2.02	1.01	0.01
S1	2	2.02	1.01	0.010
S2	2	2.02	1.01	0.01
S3	2	2.02	1.01	0.01
M1	2	2.05	1.02	0.008
M2	2	2.08	1.03	0.006
M3	2	2.12	1.06	0.005
MN	2	2.05	1.02	0.008
MD	2	2.08	1.04	0.007
MX	2	2.12	1.06	0.005

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.084	1	0.084	475.91	4.21E-09	5.11
Columns	0.0073	9	0.0008	4.58	0.01663	3.17
Error	0.0015	9	0.00017			
Total	0.093	19				

Chapter 4: Effect of Climate Change on Crop Productivity and Welfare Sensitivity Analysis for Smallholder Farmers in Malawi

Abstract

The effect of climate change on crop productivity under different crop technology options of conservation agriculture, *Falbedia abilda*, optimal fertilisation and intensive farming was analysed against the conventional subsistence farming practice. In comparison to the base year of 2010, results indicate a decrease in crop yields ranging from 15% for maize under subsistence farming to 2% under intensive farming by the 7th decade (2061- 2070). In the 7th decade, yields under conservation agriculture and agroforestry were found to be 1.6 and 1.4 times higher when compared to subsistence farming in 2010. The ratio of yield to cost of production were highest for maize under intensive farming at 12kgs/$ followed by optimal fertilisation at 8kgs/$ and subsistence framing at 4kgs/$. Choice to adapt to changes in climate effects increased total welfare by 24% and producer revenues by 44% when compared to no adaptation. The study recommends increasing intensive farming i.e. irrigation infrastructure to 5.6% and adoption of conservation agriculture and agroforestry by 22% in order to offsets the negative effects of climate change on welfare of smallholder farmers in Malawi.

Keywords: climate adaptation, crop technologies, sensitivity analysis.

4.1 Introduction

Future climate change impacts on the agricultural sector have been studied in many aspects involving crops, technologies and geographical resolution. While general guidance is construed from such studies, the variation in technology access and farmer adaptability renders generalisation of such results unhelpful (Feijt *et al.* 2016). Specific guidance for policy making for a particular region requires consideration of the regional biophysical conditions and socio-economic status of farmers in question (Chabala *et al.* 2015). However literature review, not just for Malawi but many Sub-Saharan Africa countries show that such studies are scarce and have usually been at low resolution, or involved isolated crops and mostly considered only one technology of subsistence farming. Such isolated crop and technological evaluations, render neither sufficient advice for crop diversification nor technology adaptation options.

4.2 Literature review

A number of studies have been done in analysing the effect of climate change on the agricultural sector in SSA. The usefulness of such studies depends on combination of a number of factors like geographical resolution, crops, technologies, farmer preference and economic status; and future expected demand (Vermeulen *et al.* 2012). However due to data limitations many studies do not comprehensively include such factors in their analysis.

Previous studies related to climate change like Arndt *et al.* (2012) and Saka *et al.* (2003) have focussed at regional or country level. While such reports are necessary for higher policy planning, or negotiations between countries, they may not be used to justify investments in particular agro-ecological zones. Apart from geographical resolution, the actual crops selection is also critical. In Malawi, cassava, cotton, groundnuts, maize, soybeans, tobacco, paprika, sorghum rice, sugarcane and tobacco are the major crops contributing to over 95% of total grown areas (GoM 2012b). However, other than maize not much is known regarding climate impact on other crops (Cooper *et al.* 2008; Schlenker & Lobell 2010) also see (**Chapter 1, section 1.4, Table 1:1**). Such approach derails the appreciation that cash crops are also important in attaining food security and increasing farmers' incomes to eradicate poverty (Barbier 2000; Masanjala 2006).

For instance, not much is known on the future climate effects on tobacco which is the most single important income crop in Malawi, (Nakhumwa *et al.* 1999).

Technological combinations are also important to complement crop selection. There have been tendency to analyse subsistence farming in isolation, leaving farmers and policy makers with little advice on alternative technologies (Gama *et al.* 2014; Strauss *et al.* 2012). This chapter has considered all the major crops, dominant in Malawi, in addition to range of technologies that include subsistence farming, conservation agriculture, *Falbedia albida*, optimal fertilisation and intensive farming to analyse the effect of climate change on crop productivity and welfare of smallholder farmers in Malawi.

4.3 Research questions

4.3.1 What is the effect of climate change on crop productivity under different smallholder crop technologies?

4.3.2 What are the optimal land use options to adapt to climate change effects?

4.3.3 How does climate change affect future welfare of smallholders in Malawi?

4.4 Methods

4.4.1 Data sources and model adjustment

In this chapter the scope of MASM is adjusted to cover a 60 year period from 2010 to 2070 and the cost or benefit of SOC (ζ_t . $C_{t,r}$) abatement is deactivated. Data on crop yields are an output of the EPIC biophysical model (**Chapter 2, section 2.4.6**). National population, farming population, population growth, and income levels are sourced as earlier explained (**Chapter 2, section 2.4.7**).

4.4.2 Welfare estimation

The revised consumer welfare (W) (**eq. 4:1**) resulting from decision (*d*) to adapt or not adapt is estimated as a product of consumption ($Q_{j,t,r}$) and market prices ($p_{j,t,r}$), summed over all crop products (*j*), study periods (*t*) and regions (*r*) minus the costs of production ($ç_{j,m,t,r} \,.\, L_{j,m,t,r}$), costs of storage, ($ş_{j,t,r} \,.\, S_{j,t,r}$) and costs of trade ($ţ_{j,r,\tilde{r}} \,.\, T_{j,t,r,\tilde{r}}$):

$$Max\ W = \sum_{t} \begin{pmatrix} \sum_{j,r} \left[\int \; p_{j,t,r}\left(Q_{j,t,r}\right) dQ_{j,t,r} \right] \\ - \sum_{j,m,r} \left(ç_{j,m,t,r} \cdot L_{j,m,t,r} \right) \\ - \sum_{j,\tilde{r},r} \left(ţ_{j,r,\tilde{r}} \cdot T_{j,t,r,\tilde{r}} \right) \\ - \sum_{j,m,r} \left(ş_{j,t,r} \,.\, S_{j,t,r} \right) \end{pmatrix} \qquad \textbf{(eq. 4:1)}$$

Producer revenue (R) is estimated as product of price ($p^{*}_{j,t,r}$) and demand ($Q^{*}_{j,t,r}$) summed over all crops (*j*), study periods (*t*) and regions (*r*) as in (**eq. 4:2**):

$$R = \sum_{j,\mathrm{t},r} \left(p^{*}_{j,t,r} \cdot p^{*}_{j,t,r} \right) \qquad \textbf{(eq. 4:2)}$$

4.5 Results

Before presentation of the results, a review of climate variables which are from smaller regions, but aggregated at national level are presented in (**Figure 4:1**). Mean precipitation, is expected to decrease from the 2nd decade (2011-2020) by -31mm in the 7th decade (2061-2070). This however does not explain annual precipitation distribution. The average number of rain days over the two decade (2nd and 7th) was almost the same at 103 and 104 days respectively. The mean maximum and minimum temperature increased by 1.9^{o}C. All the climate variables between the two decades were found to be significantly different at $p = 0.05$. These significant changes are expected to affect crop productivity over decades.

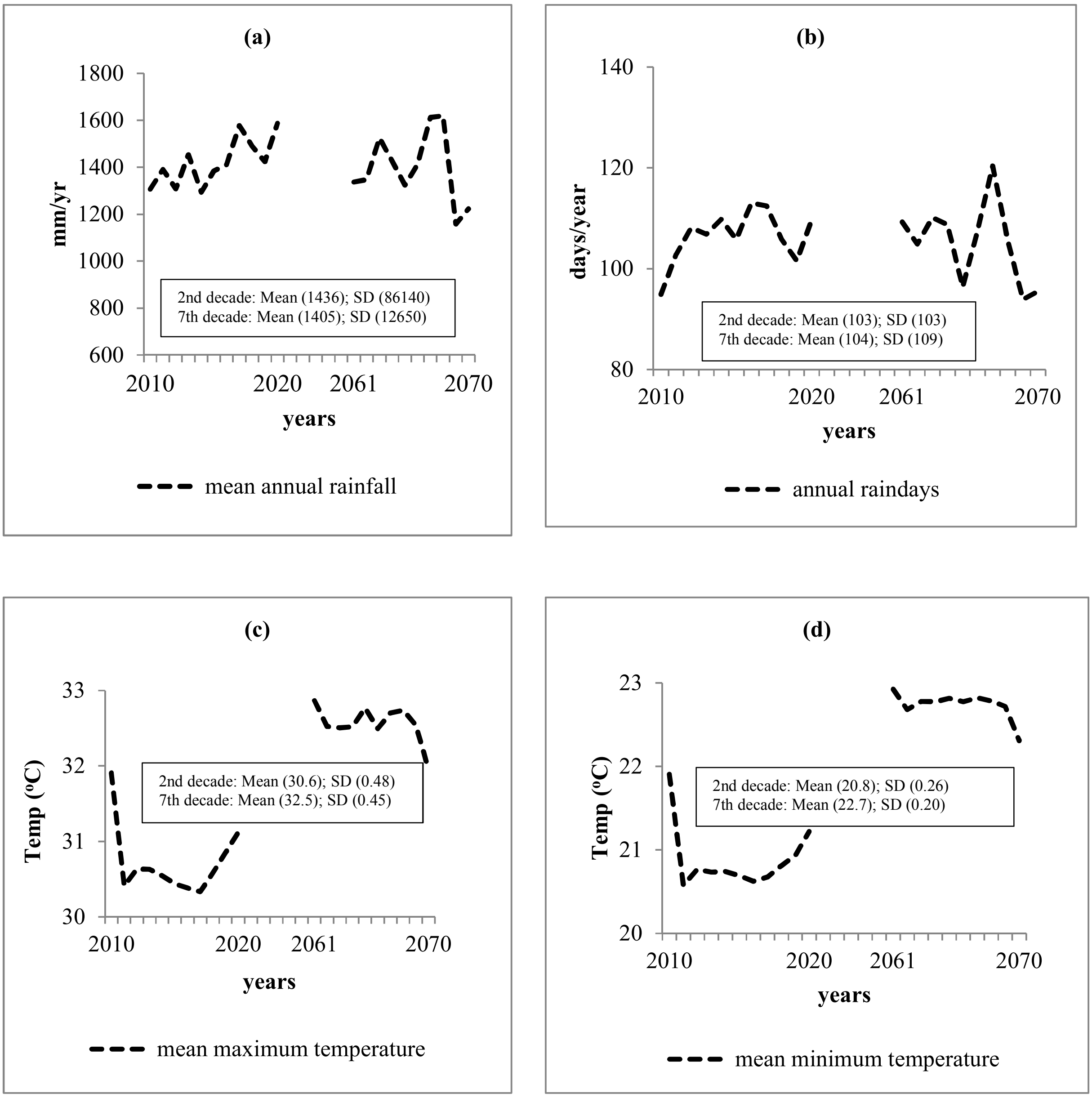


Figure 4:1. Decadal climate variables
Data source: Downscaled climate data for Malawi (2010 – 2070).

4.5.1 Climate effects on crop yield

Many variables influence yield change, in this section using regression analysis, coefficient of determination (R^2) was used to analyse rainfall variation to yield changes under different crop technologies as presented in **Table 4:1.** The results show that rainfall variability would explain yield variation in maize by 63% under optimal fertilisation (R^2 = 0.63); and 64% under subsistence farming (R^2 = 0.64) but could only account for 2% of yield variation under intensive farming (R^2 = 0.02). This indicates that rainfall variability would influence yield variability more under subsistence and optimal fertilisation, whereas intensive farming which is irrigated was least affected.

Table 4:1. Rainfall and yield coefficient of determination

Crop technology	Crop type								
	Cotton	groundnuts	Maize	Paprika	Rice	Sorghum	Soybeans	Sugarcane	Tobacco
Conservation agriculture	--	--	0.34	0.18	--	0.37	0.14	--	--
Falbedia albida	--	--	0.63	0.14	--	0.28	0.08	--	--
Intensive farming	0.02	0.05	0.01	0.001	0.17	0.12	0.06	0.07	0.08
Optimal fertilisation	0.18	0.15	0.63	0.10	0.18	0.22	0.22	0.23	0.22
Subsistence farming	0.17	0.16	0.64	0.10	0.22	0.23	0.22	0.25	0.23

The actual crop yields and yield changes are first presented as national aggregates and later in selected EPAs as shown in (**Figure 4:2; Figure 4:3; Figure 4:4; and Figure 4:6**). The crop yield changes are in references to the base year 2010. All crops apart from paprika (**Figure 4:3-d1**) experienced yield losses. Average yield change ranged from 10% to -30% for most crops and management options. The highest yield losses of up to 52% were observed under maize (**Figure 4:2-c2)** and Falbedia albida (**Figure 4:3-c2**) and soybeans under *Falbedia albida* at 48% (**Figure 4:4-g2**). Intensive farming under all crops had the lowest yield change variation at 2%. As regards EPA regions, highest yield decrease was observed in the northern region and southern region under *Falbedia albida* and conservation agriculture. In term on crops, tobacco was more affected with changes in climate across all regions when compared to maize.

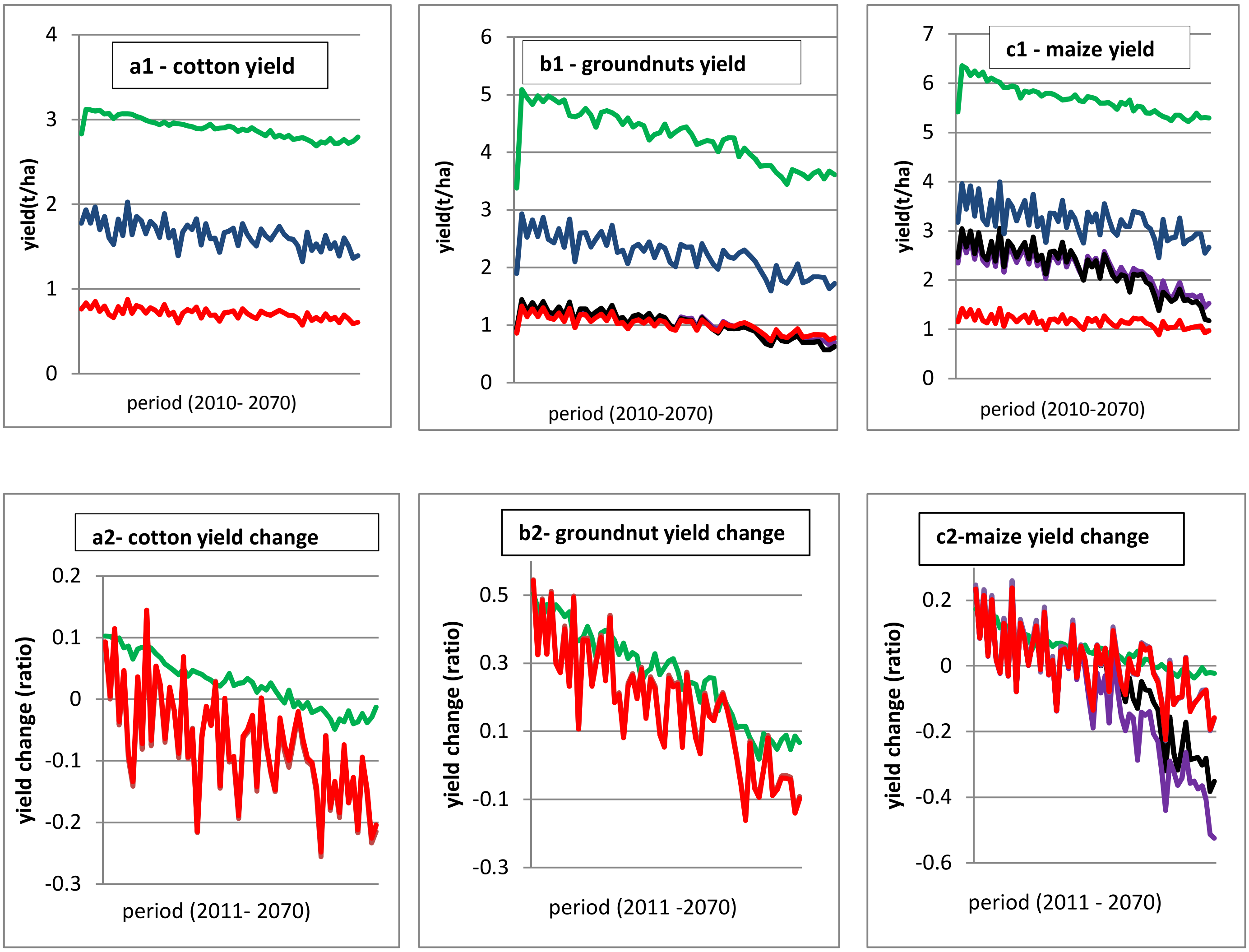


Figure 4:2. National annual crop yield and crop yield changes from EPIC simulation
Green = intensive farming; blue = optimal fertilisation; amber = *Falbedia albida*; black= conservation agriculture and red = subsistence farming, yield change (ratio) = change in reference to 2010 yield levels.

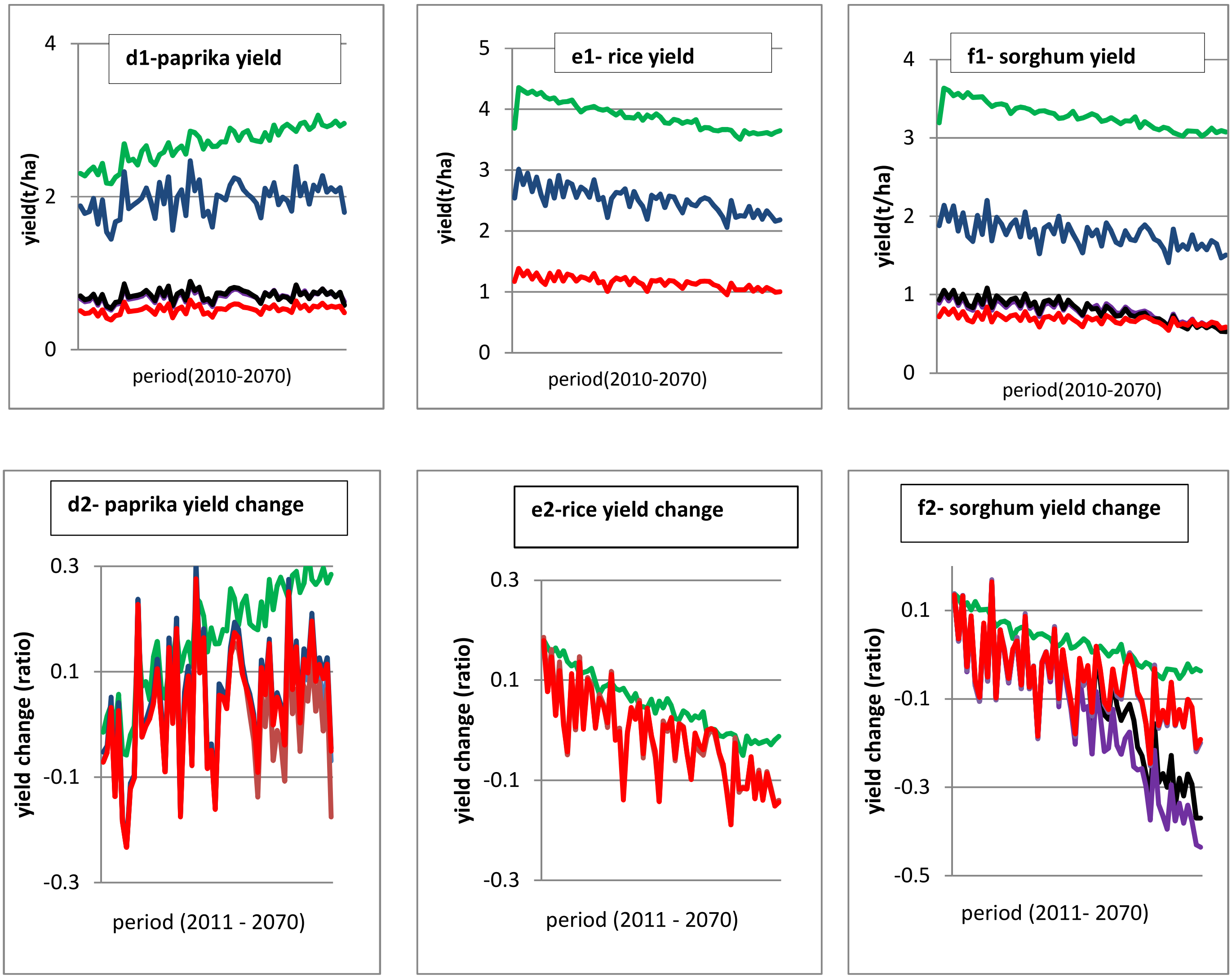


Figure 4:3 National annual crop yield and crop yield changes from EPIC simulation

Green = intensive farming; blue = optimal fertilisation; amber = *Falbedia albida*; black= conservation agriculture and red = subsistence farming, yield change (ratio) = change in reference to 2010 yield levels.

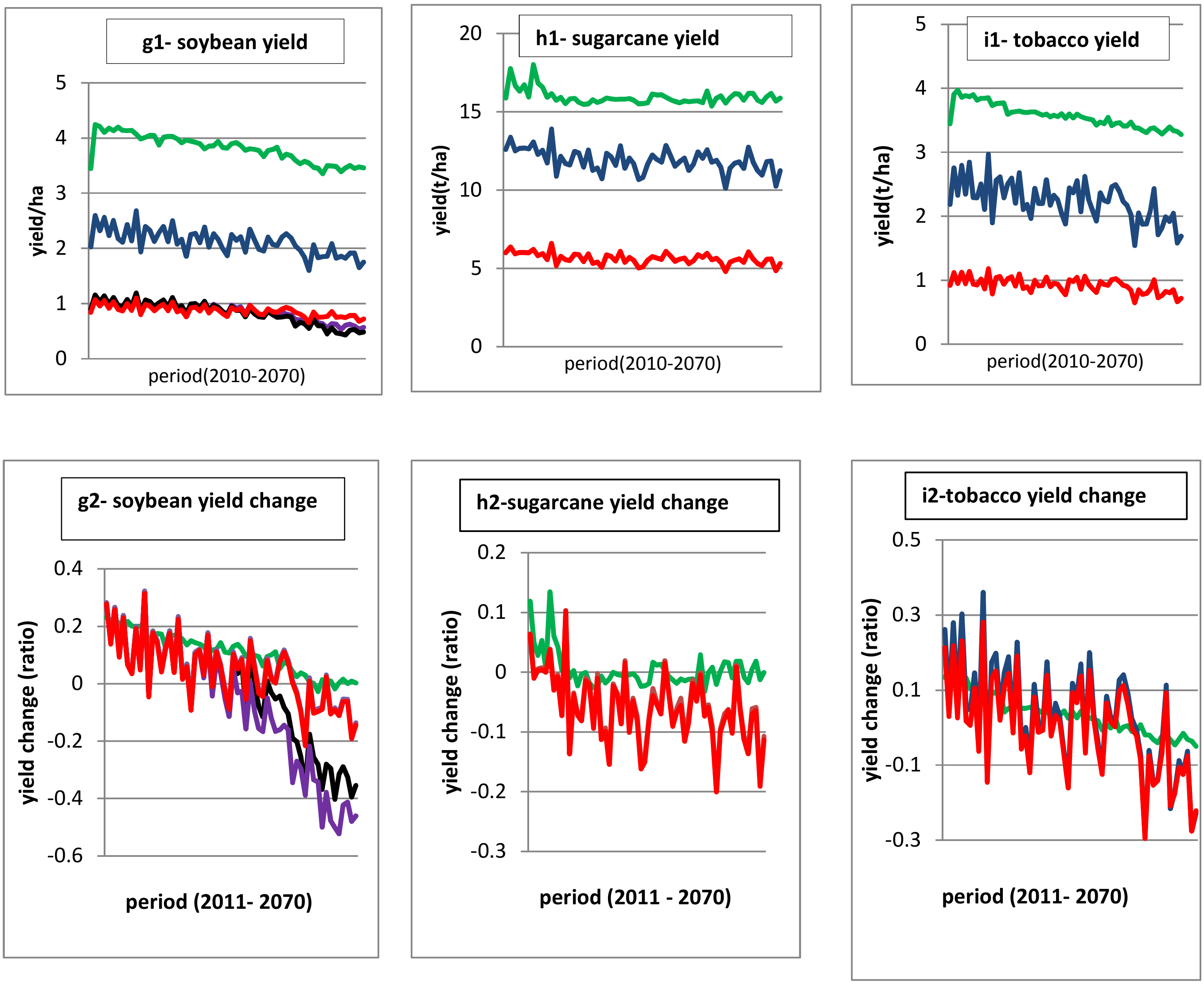
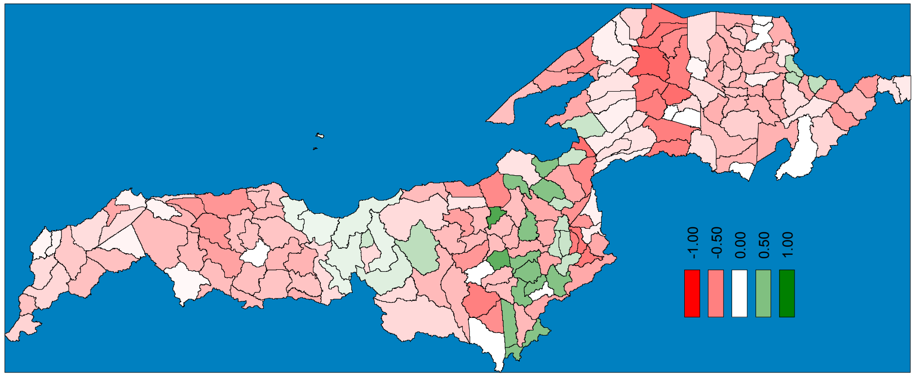
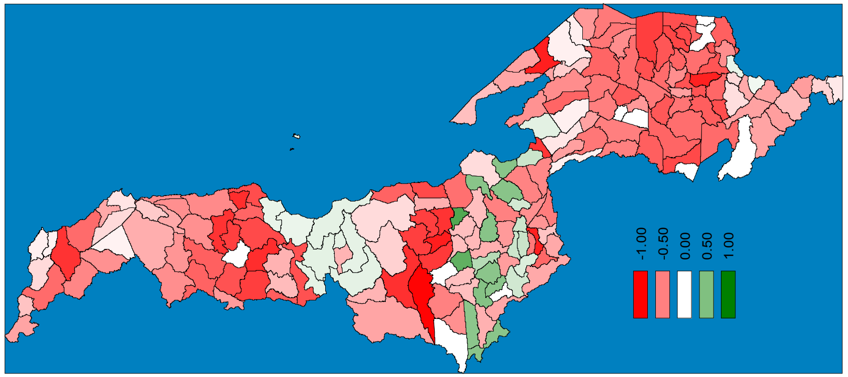


Figure 4:4. National annual crop yield and crop yield changes from EPIC simulation

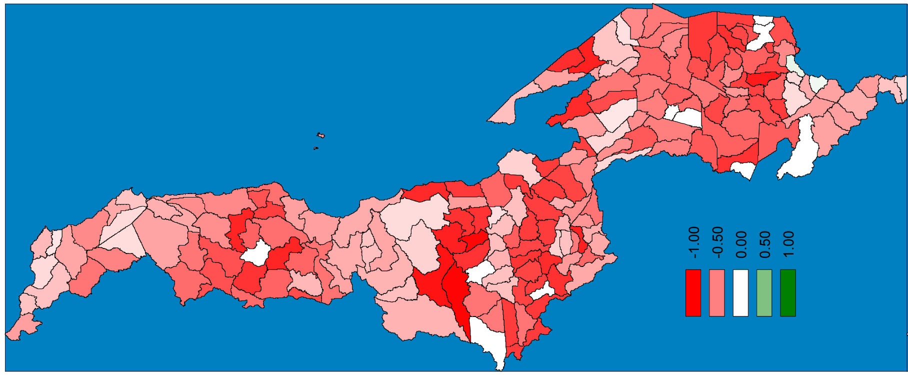
Green = intensive farming; blue = optimal fertilisation; amber = *Falbedia albida*; black= conservation agriculture and red = subsistence farming, yield change (ratio) = change in reference to 2010 yield levels



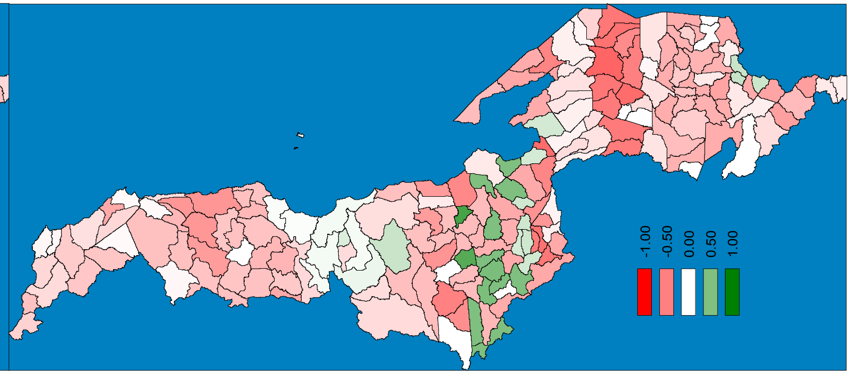
Maize yield change under subsistence farming



Maize yield change under conservation agriculture

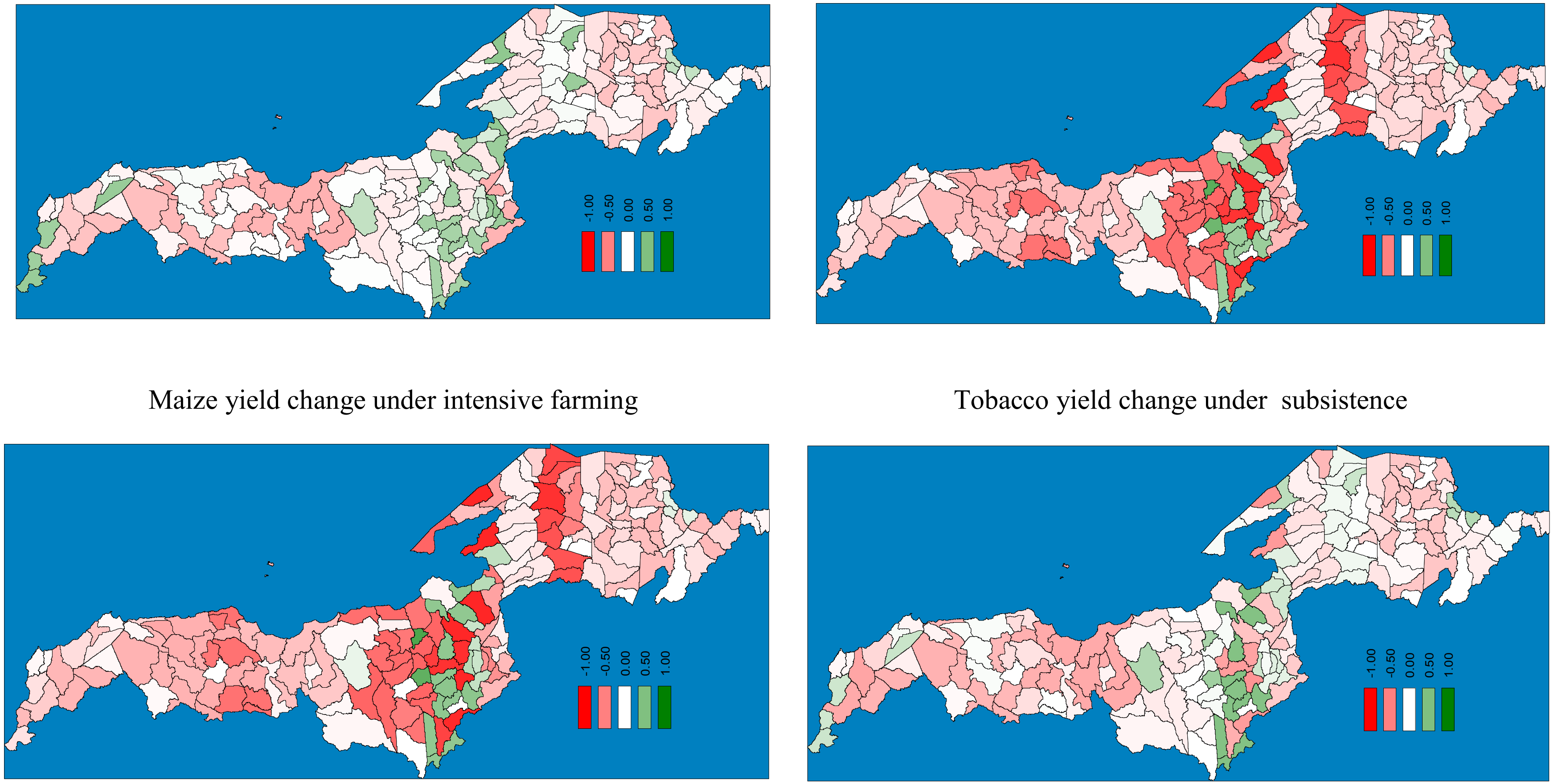


Maize yield change under *Falhebia albida*



Maize yield change under optimal fertilisation

Figure 4:5-a EPA crop yield changes under RCP 8.5



Maize yield change under intensive farming

Tobacco yield change under subsistence

Tobacco yield change under optimal fertilisation

Tobacco yield change under intensive farming

Figure 4:6-b EPA crop yield changes under RCP 8.5

4.5.2 Effect of technology shift on yield

Yield change was calculated as a ratio of yield from alternative technology to yield under subsistence farming. Shifting from subsistence to an alternative technology led to yield increase as presented in **Figure 4:7**. All technology alternatives resulted into higher crop productivity. In the 2nd decade, intensive farming had the highest yield increase compared to other technologies of up to 4.8 times for maize while the lowest was under conservation agriculture at 2.1 times. The results also showed yield change from the 2nd to the 7th decade. Intensive farming resulted into increased ratio of 5.1 times compared to subsistence farming in the 7th decade whereas the ratio reduced to 1.6 under conservation agriculture.

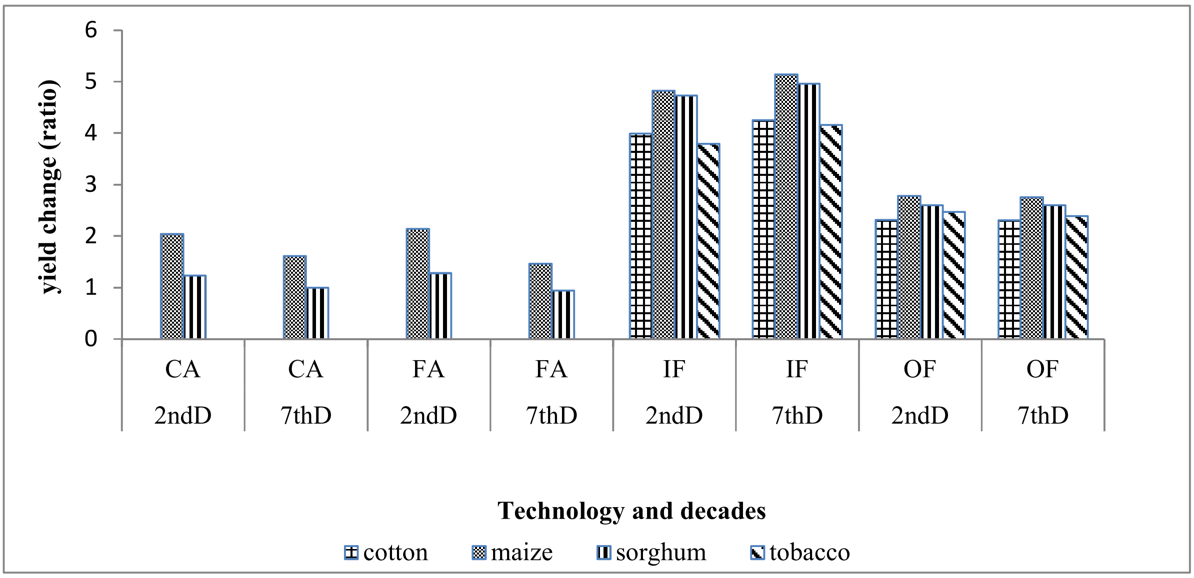


Figure 4:7. Effect of technology shifts on crop yield
CA = conservation agriculture, FA = *Falbedia albida*, IF= Intensive farming, OF = optimal fertilisation

4.5.3 Technology yield and cost of production

The ratio between crop yield and cost of production for each technology per hectare are presented in **Figure 4:8**. In the 2nd decade, intensive farming had the highest yield to cost of production at (12.2kg/$), followed by *Falbedia albida* at 10.2kgs/$ and subsistence farming being the least with 5.7kgs/$. However, the marginal yield decreased with decade to 10.4kgs/$ for intensive farming and 5.6kgs/$ for falbedia albida and 4.11kgs/$ for subsistence farming. This simply shows the effect of changes in climate on yield productivity.

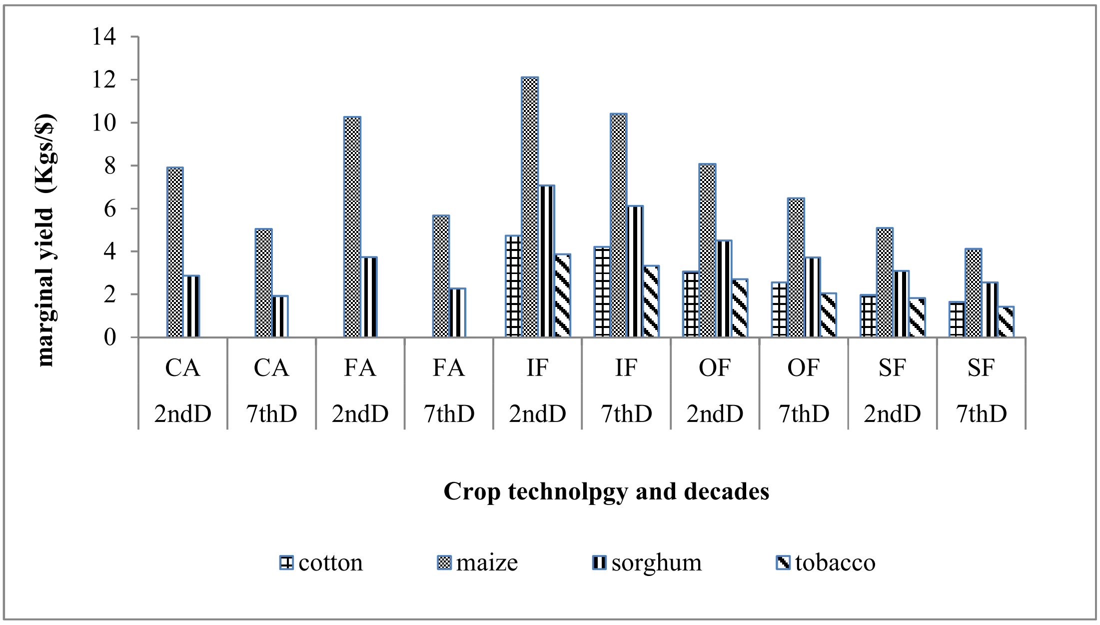


Figure 4:8. Technology crop yield cost ratio
CA = conservation agriculture, FA = *Falbedia albida*, IF= Intensive farming, OF = optimal fertilisation

4.5.4 Optimal land use options

In this section, crop choices were aggregated over farmer income groups (*f*), technologies (*m*) and regions (*r*) (Table 4:2). Slight changes were noted in terms of crop choices in all crops but they were insignificant at ($p = 0.5$). This outcome as observed in previous chapter (Chapter 3) is mainly due to crop mix equations (**see Chapter 2 section 2.4.9, (eq. 2:10**).

Table 4:2. Optimal crop choice levels at national level

	Crops areas (000 ha)			Crop mix ratios (%)		
Crop type	BAU	Optimal level (2nd Decade)	Optimal level (7th Decade)	BAU	Optimal level (2nd Decade)	Optimal level (7th Decade)
Cassava	162.421	166.884	163.46	5.78	5.73	5.74
Cotton	62.672	64.535	60.807	2.23	2.22	2.14
Groundnuts	191.464	202.702	197.054	6.82	6.96	6.92
Maize	1995.267	2044.445	2005.057	70.98	70.13	70.39
Paprika	3.100	3.513	3.305	0.12	0.13	0.12
Rice	35.256	37.560	39.657	1.26	1.29	1.4
Sorghum	101.812	105.793	100.586	3.63	3.63	3.54
Soybean	128.537	120.036	123.391	4.58	4.12	4.34
Sugarcane	16.152	20.046	18.548	0.58	0.69	0.66
Tobacco	114.587	149.819	136.894	4.08	5.14	4.81
Total	**2811.268**	**2915.333**	**2848.759**	**100**	**100**	**100**

Technology choices were also aggregated over farmer income groups (*f*), crops (*j*) and regions (*r*) as shown in **Table 4:3**. Changing from BAU to require optimal landuse levels resulted in reduced adoption of subsistence farming from 60.3% to 46.3%. Instead, subsistence farming was replaced by more productive technologies like conservation agriculture and *Falbedia albida*, which in total contributed more than 22% under both 2nd and 7th decades.

Table 4:3. Technology mix levels

Technology	Crops areas (000 ha)			Technology mix ratios (%)		
	BAU	Optimal (2nd Decade)	Optimal (7th Decade)	BAU	Optimal (2nd Decade)	Optimal (7th Decade)
Conservation agriculture	13.599	329.307	360.818	0.49	11.3	12.67
Falbedia albida	13.514	335.803	287.179	0.49	11.52	10.09
Intensive farming	119.082	142.943	159.241	4.24	4.91	5.59
Optimal fertilisation	968.509	708.7	721.975	34.46	24.31	25.35
Subsistence farming	1696.564	1398.578	1319.544	60.35	47.98	46.33
Total	**2811.268**	**2915.333**	**2848.759**	**100**	**100**	**100**

4.5.5 Welfare sensitivity analysis

The sensitivity analyses considered welfare changes on farmer decision to adapt and not to adapt, in the case where there was climate or no climate change. Results on welfare sensitivity analysis are presented in **Table 4:4**. Without climate change the model adopted 2010 yields for all time periods. It should be noted that yields in 2nd decade (2011 – 2020) were relatively higher than 2010 whilst yields in 7th Decade were relatively lower than in 2010. Results show that no adaptation under no climate change would lead to total welfare loss of 9.4% which is understandable since yields in 2nd decade were higher than 2010. Therefore climate change in 2nd decade had positive influence on consumer welfare under no adaptation. However without climate change in 2nd decade, adaptation would increase consumer welfare by 5.57%. In the 7th decade climate change had a negative effect on consumer welfare as such adaptation was necessary and beneficial.

Table 4:4. Welfare sensitivity analyses

		Type of welfare			
		Consumer welfare (Δ %)		Producer revenue (Δ %)	
Decision	Climate outcome	2nd Decade	7th Decade	2nd Decade	7th Decade
BAU (No adaptation)	Climate changes (Yield changes)	0.00	0.00	00.00	0.00
	No climate change (constant yields)	-9.44	9.57	-13.8	2.28
Optimal land use (Adaptation)	Climate changes (Yield changes)	0.02	0.24	1.03	0.44
	No climate change (constant yields)	5.57	102.11	8.64	13.60

4.6 Discussion

In the preceding section results have been presented on the effect of climate change on crop yields, optimal land use trends and welfare sensitivity analysis under different crop technologies and decision to adapt or not to adapt to effect of climate change. The following chapter discusses the significance of the results.

While there is limitation to discuss all crops results to due to inavailability of such studies in the past in SSA, a few crop results are discussed. Crop yield results indicate a general crop yield decrease which was different with each crop technology. Rainfall variability had higher determination coefficient at 0.64 and 0.63 for subsistence and optimal fertilisation while intensive farming had least coefficient. This is expected as intensive farming is irrigated, as such changes in yield would only emanate from other factors like temperature and relative humidity. Conservation agriculture had a lower coefficient of determination when compared to subsistence farming. This supports the argument that conservation agriculture improves soil water conservation as expressed by many authors (Bossio *et al.* 2010; Hatfield *et al.* 2001).

The aggregated changes in crop yield results agree with the findings of Saka *et al.* (2003) who also noted yield decrease in maize ranging from 10% to 25%. However, the results are different from Gama *et al.* (2014), who estimated maize yields increase by 5 to 10%. The difference may be due to the fact that Gama *et al.* (2014) analysed one EPA for a particular year of 2070 while this analysis considered decadal yields to avoid bias resulting from a particular year isolation. Yield cost ratios were highest for intensive farming in all the decades. This ratio increased for intensive farming in the 7th decade mainly to negative effect of climate change on yields under subsistence farming.

In order to maximise producer welfare the technology adoption rates for conservation agriculture and *Falbedia albida* increased from observed values of 0.48% to around 12% for conservation agriculture and 11.5% for *Falbedia albida*. As already discussed in Chapter 3, such levels are quite high especially considering the number of challenges that smallholder farmers face in adopting of these technologies on a larger scale (Mfune 2014). The results also show that it would be advisable to increase the component of intensive farming from the observed 4.23% to 5.54% of crop area. This increment, is however much lower when compared to the estimated irrigation area in chapter 3. The difference is that chapter 3 had food restriction requirements and subsidy support on technologies. Secondly chapter 3 only analysed the base year of 2010 in order to understand the effect of food governance on hunger eradication. As such, the model was restricted to one year. This suggests the necessity of analysing sets of years than isolated time periods to effectively design land use options.

The results under welfare show that climate change will affect welfare negatively in the 7th decade. This is shown by the consumer welfare difference between no climate and climate change effects. Secondly the welfare sensitivity analysis showed that with adaptation welfare improves by 0.24% in the 7th decade when compared to no adaptation. Producer revenues also increased by 0.44% with adaptation compared to a situation without adaptation. What is also important under these results is the need to operate at optimal level even without climate change effects. Many subsistence farmers even without climate change effects have non-optimal land use levels. This is shown from results where optimal land use under no climate change has higher welfare when compared to non-optimal land use i.e. under BAU with no climate change. From literature review no studies were found on welfare analysis on Malawian agricultural sector. However the results on producer revenues are in agreement with Gama et al (2011), who though only analysed maize for a particular EPA found that farmers who adapted to climate change effects had 5.1% more revenue than those who did not adapt.

4.7 Conclusion

In this chapter, the effect of climate change was analysed on crop productivity and welfare of smallholder farmers under different crops, crop technologies and decision to adapt or not to adapt. All technologies experienced crop yield decrease, however alternatives technologies provide better yields and yield returns than subsistence farming in all decades. Choice to adapt has positive impact on smallholder farmers' welfare while choice of no adaptation had negative effect. Apart from adapting to climate change effects farmers were also found to operate at non-optimal levels. Besides adaptation requirement to climate change, optimal land use is necessary to improve productivity

Chapter 5: The Effect of Tobacco Substitution on Smallholder Farmers Welfare and the Malawi Economy.

Abstract

Malawi is a tobacco dependent economy; as such the global anti-tobacco campaigns pose a high economic risk to country's economy. An ex-ante biophysical economic modeling approach from 2010 to 2070 was used to analyse consumer welfare, producer revenue and government forex level changes in Malawi under assumptions of continued and curtail of tobacco production. The results showed that curtail of tobacco led to consumer welfare loss of 3.3% but huge producer revenue losses of up to 44.5% and government forex earning losses of nearly 73.1%. To avert forex earnings losses, required expanding the export markets of tobacco substitute crops by atleast 2.1 times for cotton and 0.8 times for sugarcane in reference to observed levels. When tobacco was curtailed, sugarcane and groundnuts offered the best substitutes contributing 47.4% and 29.7% to total producer revenue, respectively. The study results may guide policy decisions on optimal tobacco diversification options in view of global tobacco market instabilities or curtail of its production.

Key words: tobacco substitute crops; crop diversification, bioeconomic modeling

5.1 Introduction

Tobacco is considered, the "green gold" in Malawi, (Negri & Porto 2016; Yasuharu & LaStarria-CorNhieL 2015). However, the crop faces heavy criticism regarding its environmental and health effects, leading to huge anti-tobacco campaigns (Keyser 2007). Such anti-tobacco campaigns have over the years, contributed to the instability of the tobacco global markets and its profitability (Guindon *et al.* 2015; Wakefield *et al.* 2008). Consideration for diversification options is therefore critical for both farmers' welfare and the Malawi economy. Though a number of Malawi government policies and strategies seek to diversify tobacco (GoM 2011a; GoM 2010a), no comprehensive analysis has been done to understand the effect of tobacco substitution on farmers' income and government's forex earning base or recommendation on levels of substitution. To fill such knowledge gaps, this chapter, analysed diversification options and their respective effect on farmer income and forex earning levels under assumptions of continued and curtailed tobacco production.

5.2 Literature review

The importance of tobacco to Malawi economy is portrayed in many ways. Since the 1960s, it has consistently contributed between 60% and 70% of the forex earnings (forex), (**Figure 5:1**), (GoM 2010b); 13% of the GDP; 23% of the government's tax base, (Tchale & Keyser 2010) and 40% of total employment (Tsonga & Mataya 2001).

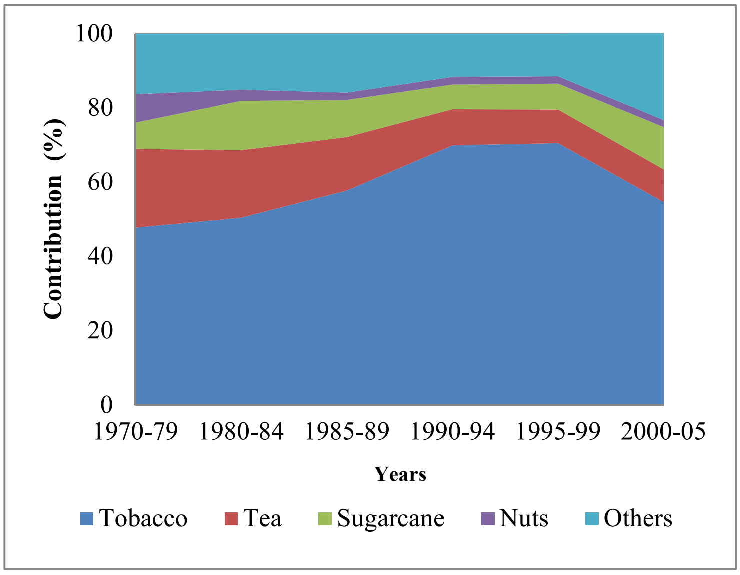


Figure 5:1. Contribution of tobacco to Malawi export base
Source:Adopted from (GoM 2010b)

Even though tobacco plays such a critical role in Malawi, strong divergent views exist regarding the curtailing of tobacco production in the world. The main argument advanced by anti-tobacco campaigns is that consumption of tobacco has casual links to cancer (Lecours *et al.* 2012; Stephen 2016). In addition other studies indicate that tobacco is an extremely input expensive crop which leaves the majority of smallholder farmers in great indebtness, (WHO 2016). Others like, Markowitz (2014) and Novotny & Slaughter (2014) have linked tobacco to environmental problems, mainly resulting from use of pesticides and deforestation which are caused by expansion of tobacco crop area and demand of firewood for curling. Additionally, working conditions in tobacco farms have also come under heavy criticism, especially regarding utilisation of child labour (Otanez *et al.* 2006).

Reciprocally, tobacco producing countries and marketing companies have been aggressive in promoting tobacco production and its consumption. Firstly, the high tobacco production costs are disputed as not being unique to tobacco itself, as the suggested substitute crops like tomato and cotton are found to be equally or even more expensive to produce and utilize more damaging pesticides than tobacco (Keyser 2007). Cases of rampant deforestation rates in countries like Brazil and Argentina, which are caused by tobacco substitutes like soybeans and livestock (Barona *et al.* 2010), buttress the argument advanced by pro-tobacco activists that curtail of tobacco may not necessarily be a solution to deforestation problems. Whereas Malawi has one of the highest deforestation rates in Southern Africa, Nsiku & Botha (2007) observed that over 80% of total tobacco production in Malawi does not require firewood for curing, suggesting that most of the deforestation is not caused by tobacco production.

The battle and debate to curtail or not to curtail tobacco is far from over. While developed countries have reduced production by 1.29% since the emergence of anti-tobacco campaigns in the early 1990s, developing countries have increased production by 5.68% leading to a steady global increase of 1.02% per annum (Jaffe 2003). Similarly, despite the decrease in per-capita consumption, the number of smokers has steadily increased over the years (Stuckler *et al.* 2012; Ng *et al.* 2014). Guindon *et al.* (2015) estimated that the number of tobacco smokers had increased from 1.1 billion in 1990 to 1.3 billion in 2010 and is further projected to reach 1.7 billion by 2025. Malawi statistics also indicate that while 50% of estate farmers have abandoned tobacco production in the last 20 years, smallholder farmers have almost tripled total production from 49 million to 113 million tons per year (Jaffe 2003). Clearly pro-tobacco activists seem to currently have an edge, but complacency cannot be an option for tobacco dependent countries like Malawi, as anti-tobacco campaigns are led by powerful international organisations such as the World Bank and the World Health Organisation Framework Convention on Tobacco Control (FCTC).

5.3 Research questions

5.3.1 What is the effect of tobacco substitution to welfare of smallholder farmers in Malawi?

5.3.2 What options exist to minimise welfare losses?

5.4 Theoretic background

Even though, little is known regarding future tobacco diversification options or the effect of such options on farmer income and government forex earning levels in Malawi, previous studies on tobacco substitution include Jaffe (2003); Keyser (2007); Nakhumwa *et al.* (1999); Tsonga & Mataya (2001). Most of these studies partly used Gross Margin Analysis (GMA) to analyse tobacco susbsitute crops. While widely used, the GMA methodology disregards demand and supply principles and also fails to analyse alternative crop combinations for farmers.

In order to improve on the GMA Analysis, Nakhumwa *et al.* (1999) combined Policy Objective Analysis Matrix (POAM) and Domestic Resource Cost Ratios (DRC) methods. POAM uses subjective scores decided by analysts which consider crop aspects like drought resistance and market potential to measure resource use efficiency while DRC (**eq. 5:1**), estimates resource opportunity cost of importing or producing a product within a country (Little & Mirrlees 1974) .

$$D_j = X_j^r \Big/ (V_j - X_j^{\tilde{r}}) \qquad \textbf{(eq. 5:1)}$$

Where (D_j) is DRC ratio of crop *(j)* and $(X_j^{\tilde{r}})$ is the cost of producing product (*j*) locally (*r*), (V_j) is the added value of crop (*j*) and $(X_j^{\tilde{r}})$ is the cost of crop (*j*) at foreign market $(\tilde{r})$. Crops with high DRC ratios are rated as having low comparative advantage and consequently not selected as potential tobacco substitutes. Like GMA, both POAM and DRC are unable to recommend required crop combinations.

With an aim to have a strong backup from stakeholders and policy makers on potential tobacco substitute crops, Tsonga & Mataya (2001) resorted to the Multiple Objective Policy Analysis Matrix (MOPAM) method. Similar to POAM, MOAP also uses subjective scores as agreed by stakeholders on different crop aspects i.e. research backup, employment potential, area grown, food security, drought tolerance and availability of markets to select substitute crops. While consensus from stakeholder and policy makers is essential component for planning, as already noted there was no guidance of actual levels of crop substitution.

The literature review did not find any study that assessed future effect of curtail of tobacco on farmers income or government forex base. Building from previous studies which used post-ante, GMA, DRC, MAP and MOAP and ended up with a list of tobacco substitute crops, this chapter uses ex-anti bioeconomic modeling approach, in order to incorporate future scenarios of climate change and population growth to estimate required tobacco substitute crop levels and analyse the effect of such options on farmer income levels and government forex base.

5.5 Methods

5.5.1 Regional scope

As already stated in chapter one, the entire country of Malawi was studied using a bottom-up regional aggregation approach. In this chapter land use options are analysed, aggregated and presented for each agro-ecological zone (**Figure 5:2**) whereas the effect of such options on forex and producer revenue was aggregated at national level.

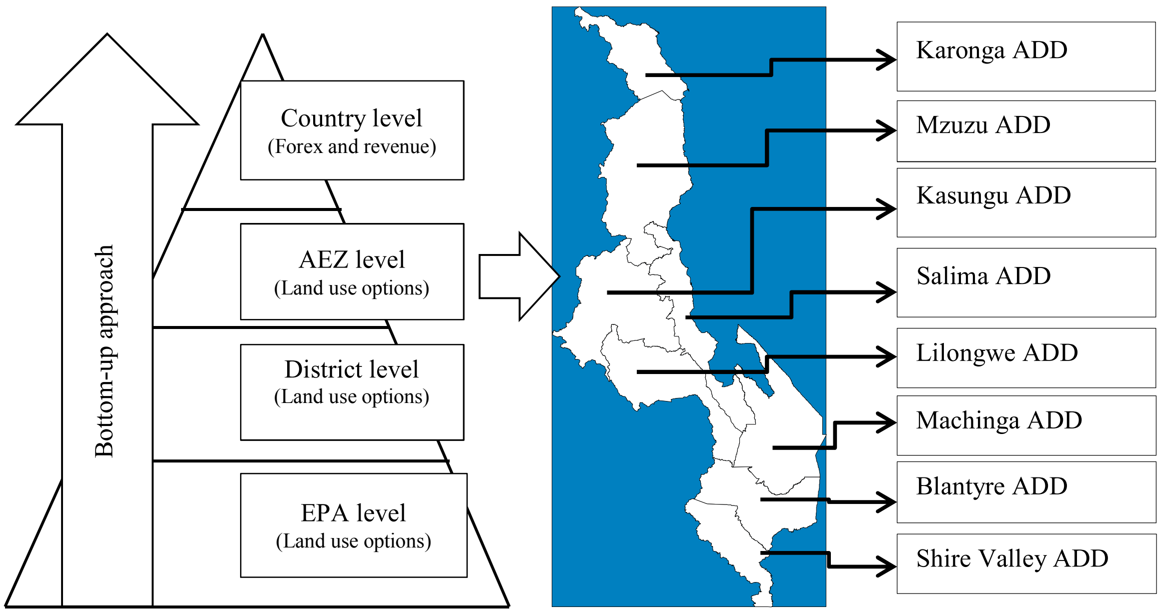


Figure 5:2. Data aggregation levels for tobacco substitution.

5.5.2 Crop selection criteria

Selection of potential tobacco substitute crops (**Figure 5:3**) was built on the process started by Nakhumwa *et al.* (1999) and Tsonga & Mataya (2001). Nakhumwa *et al.* (1999) and Tsonga & Mataya (2001) selected 7 and 8 tobacco substitute crops from 109 and 36 alternatives, respectively. While maize and sorghum appeared on the list by Nakhumwa *et al.* (1999), these food crops were not recommended for export markets but for internal consumption as a means of saving forex. As Malawi, is largely a food insecure country (Harrigan 2008; Miller *et al.* 2011) and as this study focused on the potential of crops to generate forex, all food crops were therefore removed from the analysis. Recently, through the Greenbelt Initiative, the Government of Malawi has been promoting sugarcane production and processing among smallholder farmers (Chinsinga *et al.* 2013; Kalinga-Chirwa *et al.* 2011). This chapter had therefore, included sugarcane on the list of potential tobacco substitute crops.

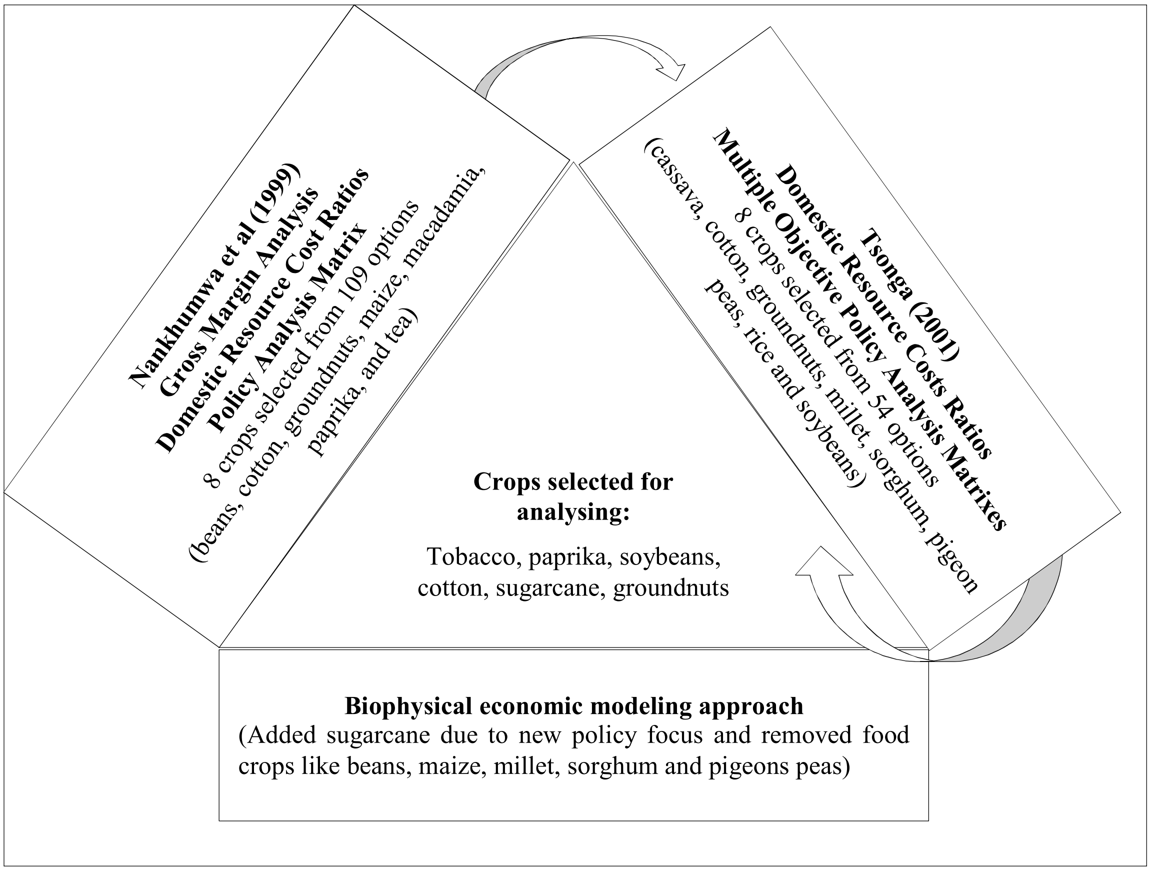


Figure 5:3. Process and criteria for selecting tobacco substitute crops

5.5.3 MASM adjustment

The Model scope is adjusted to cover a period of 60 years and analyses crops that were largely agreed by stakeholders as potential tobacco substitute crops (Tsonga & Mataya 2001). The restriction on minimum food requirements was relaxed i.e. zero values since selected crops are non-food crops. Many of the selected crops have handling and temporal storage infrastructure for export other than storage for trade in other years; as such value of storage was deactivated for all cash crops. The chapter also analysed selected technologies like subsistence, optimal fertilisation and intensive farming and skipped conservation agriculture and *Falbedia albida* since most of the selected crops did not use such technologies. Lastly the chapter did not consider the benefits or cost of soil degradation resulting from choice of a particular technology.

5.5.4 Diversification scenario options

This chapter considered diversification as altering the crop mix levels in addition to market expansion of tobacco substitute's crops in the Malawi agricultural sector in order to minimise welfare losses resulting from tobacco curtail. Firstly, a decision is taken to curtail or continue with tobacco production and welfare (total welfare, producer revenue and forex earnings) are analysed under each decision with different land use outcomes as presented in (**Figure 5:4**). After analysing the welfare under both decisions, the government or farmers may take measures to avert welfare losses (**See section 5.5.8**)

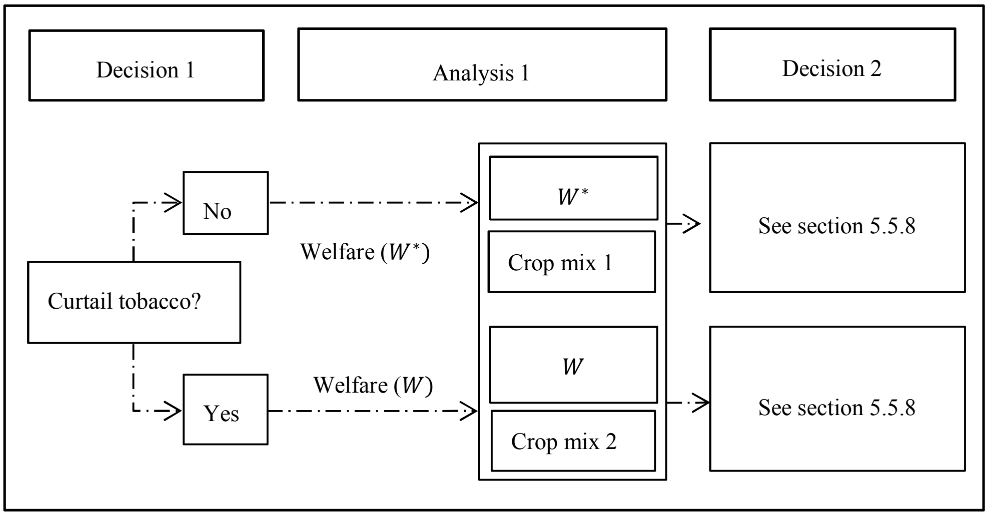


Figure 5:4. Tobacco substitution scenarios

5.5.5 Forex earnings

Forex earnings (F) in (**eq. 5:2**) were estimated as a product of export crop demand ($Q_{j,t,\tilde{r}}$) and export crop price ($p_{j,t,\tilde{r}}$) summed over all crop products (j), all study periods (t) and all regions ($\tilde{r}$). Where ($\tilde{r}$) is export region.:

$$F = \sum_{j,\tilde{r},t} \left(p_{j,t,\tilde{r}} \cdot Q_{j,t,\tilde{r}}\right) \qquad \textit{(eq. 5:2)}$$

5.5.6 Options to avert forex losses

As tobacco is major contributor to government forex and producer revenue whenever losses are made due to curtail of tobacco, government or famers take necessary measures to avert the losses. Using forex as an example, this section outlines how forex losses may be averted (**Figure 5:5**). The variable (F) represents forex levels under "curtail" whereas (F^*) is forex level under continued tobacco production, "continue" scenario. If curtailing of tobacco leads to forex gain ($F > F^*$) then there is no need to change land use options but if it leads to forex loss ($F^* > F$), then land use options have to be readjusted.

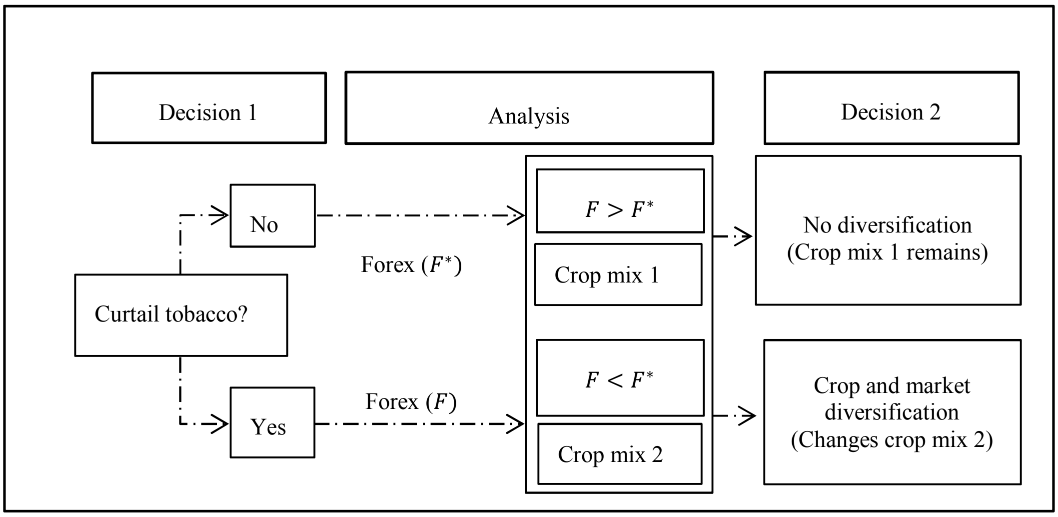


Figure 5:5. Diagrammatic outline of options to avert forex losses

Land use options may be readjusted following decision by government and farmers to increase external market opportunities (dQ_j) for tobacco substitute crops (**Figure 5:6**). The assumption is that there is potential for external markets for other crops which the government or farmers have not fully established and that the price at international ($p_{j,t,\tilde{r}}$) remains the same despite Malawi increasing its production. Since land use investments cover a period of years. The average ($\bar{p}_j$) other than annual ($p_{j,t,\tilde{r}}$) external product price is used, just as the average ($\bar{\gamma}_{j,m,r}$) other than the annual ($\bar{\gamma}_{j,m,t,r}$) crop yield is used. To minimise yield variations over the years, intensive farming, (m = *intensive farming*) which has relatively stable yield is selected.

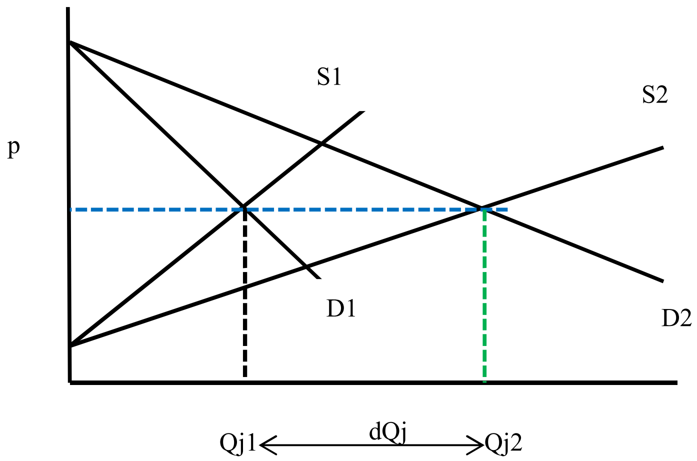


Figure 5:6. Increased external consumption to avert forex loss
blue = constant prices at external market

Change in (dQ_j) would be increased until there is zero forex loss ($F^* = F$) as presented in equation **(eq. 5:3)**. Expansion of external market factor (dQ_j), would then lead to adjustments in crop mix levels at national level (L_j^+) **(eq. 5:4)**.

$$dQ_j = {(F^* - F)}\Big/{\bar{p}_j} \qquad \forall_j \qquad \textbf{(eq. 5:3)}$$

$$L_j^{+} = \sum_{m,r} {dQ_j}\Big/{\bar{Y}_{j,\text{"intensive"},r}} \qquad \forall_j \qquad \textbf{(eq. 5:4)}$$

5.6 Results

5.6.1 Cultivate area levels aggregated at national level

Crop area levels in hectares at national level are presented in **Table 5:1** The difference between crop areas under observed and continue indicate that the observed crop areas as practiced by farmers) were non-optimal. For instance, in order to attain economic efficiency, sugarcane required higher crop areas while cotton and soybeans require lower crop areas than observed. The results also showed dominance of groundnuts at 37.63% (continue), which increased further to 49.89% (curtail). The decision to curtail tobacco also resulted in reduction of crop area level of -21.9% at national level.

Table 5:1. Effect of tobacco decision on national crop area levels

Decision	Crop mix (%)						Totals	
	Cotton	Groundnuts	Paprika	Soybeans	Sugarcane	Tobacco	(1000ha)	Area (Δ %)
Observed	12.12	37.05	0.59	24.87	3.12	22.22	514.276	0.0
Continue	11.39	37.63	0.58	22.08	3.48	24.80	538.417	4.6
Curtail	13.78	49.89	1.01	31.12	4.18	0.00	401.878	-21.9

Observed = level of crop activity as observed from farmers, continue = continue to tobacco production, curtail = stop production of tobacco, area (Δ%) = area percent change relative to observed crop areas

5.6.2 Cultivated area levels in Agricultural Divisions

In order to guide policy planning at lower levels, crop areas were further analysed for each of the eight (8) Agricultural Development Divisions (ADDs), in the three (3) administrative regions of north, centre and south.

5.6.3 Cultivated area levels for Northern region

The Northern region of Malawi has two ADDs which include Karonga and Mzuzu (KRADD and MZADD) and the respective crop area levels are presented in **Table 5:2**. Just like with national crop area levels, the observed crop area levels were non-optimal since they were different to the continued crop area levels in both ADDs. Both ADDs also showed dominance of groundnuts and soybeans contributing a total of 73.5% and 54.0% (continue) for KRADD and MZADD, respectively. The contribution of the two crops became more prominent when tobacco was curtailed, rising to 91.9% and 98.5% (curtail) in KRADD and MZADD, respectively. Similar to trends at national level, curtail of tobacco led to decreased crop area level of the selected crops by -5.6% and -2.7% for KRADD and MZADD respectively.

Table 5:2. Effect of tobacco decision on Northern region crop area levels

ADD	Decision	Crop mix (%)						Totals	
		Cotton	Groundnuts	Paprika	Soybeans	Sugarcane	Tobacco	(1000ha)	Area (Δ %)
KRADD	Observed	9.93	41.6	0.15	32.44	0.11	15.8	20.043	0.00
	Continue	8.36	41.38	0.18	29.72	0.13	20.25	17.05	-14.9
	Curtail	7.23	57.68	0.26	34.65	0.20	0.00	18.92	-5.61
MZADD	Observed	0.04	42.45	0.49	16.19	0.05	40.81	59.345	0.00
	Continue	0.05	37.68	0.51	13.84	0.06	47.88	72.946	22.91
	Curtail	0.09	75.13	1.19	23.49	0.13	0.00	57.332	-2.76

Observed = level of crop activity as observed from farmers, continue = continue to tobacco production, curtail = stop production of tobacco, area (Δ%) = area percent change relative to observed crop areas

5.6.4 Cultivated area levels for Central region

Central region is composed of three ADDs of Kasungu, Salima and Lilongwe (KADD, SADD, and LADD) and its crop area levels are presented in **Table 5:3.** Whilst the entire country is largely agrobased, the central region is considered the main agricultural region. Similar to northern region, observed crop areas in central region were also non-optimal. For instance, groundnuts crop area needed to be decreased from 42.7% (observed) to 38.6% (continue) for KADD, 29.28% (observed) to 31.7% (continue) for LADD and from 25.03% (observed) to 26.05% (continue) for SADD. When tobacco was curtailed, there was also dominance of groundnuts and soybean in KADD and LADD, contributing a total 97.7% and 89.6% (curtail) of total crop areas, respectively. For SADD, sugarcane had the highest contribution at 38.02%, followed by groundnuts at 30.71 % and soybean at 20.60% after curtail of tobacco.

Table 5:3. Effect of tobacco decision on Central region crop area levels

ADD	Decision	Crop contribution to total croparea						Totals	
		Cotton	Groundnuts	Paprika	Soybeans	Sugarcane	Tobacco	(1000ha)	Area (Δ %)
KADD	Observed	0.54	42.27	0.41	22.21	0.04	0.54	131.931	0.00
	Continue	0.48	38.60	0.41	18.49	0.04	0.48	72.503	-45.04
	Curtail	1.41	57.72	0.75	40.06	0.09	1.41	30.627	-76.78
SADD	Observed	15.49	25.03	0.35	27.81	19.98	15.49	25.936	0.00
	Continue	12.83	26.05	0.37	22.74	23.28	12.83	16.865	-34.97
	Curtail	10.11	30.71	0.58	20.60	38.02	10.11	8.871	-65.79
LADD	Observed	11.97	29.28	2.00	29.95	0.04	11.97	86.717	0.00
	Continue	8.83	31.72	1.89	26.56	0.05	8.83	95.967	10.66
	Curtail	7.94	56.07	2.51	33.45	0.06	7.94	95.099	9.66

Observed = level of crop activity as observed from farmers, continue = continue to tobacco production, curtail = stop production of tobacco, area (Δ%) = area percent change relative to observed crop areas

5.6.5 Cultivated area area levels in Southern region

The Southern region is also divided into 3 ADDs of Machinga, Blantyre and Shire Valley (MADD, BLADD, and SVADD). Crop investments for southern region are presented in **Table 5:4.** The region was also noted to have agricultural activity levels being non-optimal as portrayed by the differences under observed and continue. The southern region had the lowest observed tobacco crop mix ratios at 8.2% for MADD; 14.6% for BLADD and 0.6% for SVADD. Regardless of the decision to continue or curtail tobacco production, groundnuts and soybean remained the most important crops in terms of crop area in MADD and BLADD, contributing in both cases over 70% of total crop area. Regardless of the decision to curtail or not to curtail tobacco, cotton and sugarcane occupied over 80% of the total crop area among the selected crops in SVADD. Curtail of tobacco led to reduced crop areas of 14.73% (MADD) and 5.4% (SVADD) but an increase of 39.27% (BLADD).

Table 5:4. Effect of tobacco decision on Southern region crop area levels

		Crop contribution to total croparea						Totals	
ADD	Decision	Cotton	Groundnuts	Paprika	Soybeans	Sugarcane	Tobacco	(1000ha)	Area (Δ %)
MADD	Observed	16.85	42.05	0.09	32.79	0.05	8.20	99.224	0.00
	Continue	12.95	46.88	0.09	28.18	0.05	11.88	119.75	20.65
	Curtail	17.66	48.14	0.09	34.08	0.06	0.00	84.608	-14.7
BLADD	Observed	5.81	50.2	0.59	28.65	0.18	14.6	45.4	0.00
	Continue	9.90	44.71	0.50	25.45	0.28	19.18	90.679	99.73
	Curtail	12.87	42.46	0.91	43.31	0.48	0.00	63.23	39.27
SVADD	Observed	56.70	10.71	0.07	8.35	23.29	0.90	45.68	0.00
	Continue	46.45	16.4	0.10	8.03	27.32	1.73	52.662	15.28
	Curtail	51.02	12.18	0.08	6.86	29.89	0.00	43.195	-5.44

Observed = level of crop activity as observed from farmers, continue = continue to tobacco production, curtail = stop production of tobacco, area (Δ%) = area percent change relative to observed crop areas

5.6.6 Producer revenue and forex levels

Figure 5:7 presents results on crop contribution to producer revenue and forex base under decision to continue or curtail tobacco as displayed in **Figure 5:7-a**. The decision to continue with tobacco production, leads tobacco to contributing over 45.1% of producer revenue, followed by sugarcane at 26.39% and groundnuts with 15.71%. When tobacco was curtailed, sugarcane became the main income earner for farmers contributing 47.43% followed by groundnuts at 29.13% and soybeans with 14.81%. Similar trends were also observed with forex generation (**Figure 5:7-b**), where tobacco contributed over 75% of forex base but when curtailed, sugarcane became the major forex earner with 44.46% followed groundnuts with 23.37% and cotton with 17.4%.

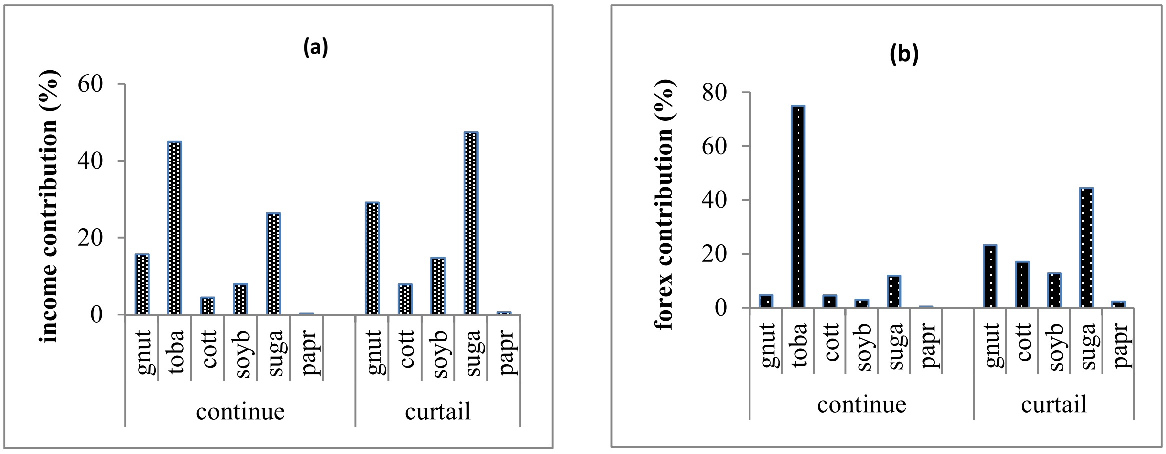


Figure 5:7. Crop contribution to producer revenue and forex base

5.6.7 Welfare changes

Table 5:5 presents results on welfare changes. Curtail of tobacco results in relatively low consumer welfare loss of 3.3%, high producer revenue of 44.4% and forex base loss of 73.1%. The loss in consumer welfare is much lower as Malawi consumers are not the primary consumers of tobacco or most of the selected crops apart from groundnuts.

Table 5:5. Effect of tobacco decision on welfare changes

Decision	Consumer welfare		Producer Revenue		Forex base	
	Amount ($1E6)	Loss (%)	Amount ($1E6)	Loss (%)	Amount ($1E6)	Loss (%)
Continue	45,026	--	41,128	--	24,688	--
Curtail	43,527	-3.3	22,864	-44.4	6,636	-73.1

5.6.8 Options to avert forex loss

As shown in **Table 5:5** curtail of tobacco resulted into government forex base loss of 73.1% ($6,636 Million). In order to avert forex losses there is need to increase external market opportunities (**see (eq. 5:3**). The required crop area increase and the adjusted areas are presented at national level are presented **Table 5:6.** The highest increase for external market are for paprika (39.2) and lowest for sugarcane (0.87). The lowest area to adjust was with sugarcane with 14,616 hectares increment and the highest under paprika at 98,700 hectares. Estimated production costs under intensive farming indicate that sugarcane would be the least expensive crop to produce in order to avert forex loss. The decision on which crop to choose depends on actual market expansion that the government may manage to negotiate with other countries.

Table 5:6. Required market expansion to avert forex losses

Crop	Expansion of external market (dQ_j)	Area under curtail (1000ha)	New required areas (1000ha)	Estimated extra cost of production from adjusted areas ($Million)
Cotton	2.1	55.378	82.961	32.39
Groundnuts	0.8	200.496	76.181	14.85
Paprika	39.2	4.058	98.700	19.94
Soybean	1.2	125.064	95.750	22.30
Sugarcane	0.9	16.798	14.616	11.60

5.7 Discussion

This chapter analysed the effect of continuing or curtailing tobacco production under different diversification options on total welfare, consumer welfare, and producer revenue and government forex earning levels. The following section presents a discussion on the land use, consumer surplus, and producer revenue and forex base.

The observed farmer crop activity levels, at both national and ADD level were found to be non-optimal. For smallholder farmers, failure to operate at optimal levels may be a result of many aspects like unavailability of seeds, accessibility of markets and lack of information. As regards tobacco substitute crops, groundnuts and soybeans remained the most important crops, contributing over 80% to the crop area in many ADDs like KRADD, MZADD, LADD and BLADD. Groundnuts and soybean are already widely grown crops in Malawi and smallholder farmer usually grow such crops without application of fertilisers, which explains why they occupy a higher proportion of crop area among smallholder farmers. Additionally, such crops do not require infrastructure investments for production like sugarcane. Sugarcane was found to be more suitable in SADD and SVADD, which apparently agree with target areas for the Greenbelt Initiative (Kalinga-Chirwa *et al.* 2011). Cotton was the single leading crop for SVADD, where it contributed about 51.02% of the total crop area. As SVADD was observed with the least tobacco crop mix ratio of 0.6%, (observed), means that adjusting to tobacco curtail would be easier among farmers, as they would simply continue producing cotton and sugarcane, the main observed crops in the region.

There was a decrease in all types of welfare apart from Malawian consumer welfare. The results clearly showed that curtail of tobacco would results in consumer welfare loss of 3.33%, producer revenue losses of 44.5% and forex earning losses of 73.1%. As noted, Malawian consumers had a slight increase in welfare of 0.3%. This is mainly due to the fact that Malawian consumers are not primary consumers of the selected crops. With curtail of tobacco, the local consumers would benefit from increased production of other crops like groundnuts. The results on producer revenue and government forex base losses agree to historical observation where tobacco has for decades contributed between 60% to 80% of forex earning base and 40% of farmers income (Tchale & Keyser 2010). The huge losses of forex base would have direct effect on importation of chemical fertilisers, medicines and fossils fuels among other important goods. This in the end could affect the entire population including the local consumers who seem not to be affected directly from the analysis.

These results are also in agreement with the findings of Van der Merwe (1998) who noted that curtail of tobacco would result in net income and employment loss in Zimbabwe. In contrast, though, the results were found to be different to McNicoll & Boyle (1992), who noted that curtail of tobacco had increased job creation in Glasgow. The differences in the results outcome are well explained by Jacobs *et al.* (2000), who noted that curtail of tobacco production for near 100% producers and exporters of tobacco (like Malawi and Zimbabwe), had net income and job losses whilst major tobacco consumer countries (like Canada and UK) had net job creation arising from increased expenditure in other sectors. Studies by (Jaffe 2003) found that tobacco substitute crops, like tomato and cotton were more profitable than tobacco. The difference in the results by Jaffe (2003), would be attributed to use of GMA metholody, which did not consider demand restrictions, otherwise the substitute crops would have been found to be less profitable than tobacco.

To avert forex earning losses required to expand export markets ranging from 0.87 times for sugarcane, 2.1 for cotton and 39.23 times for paprika. The results show that other crops require more land to cover up the forex deficit like paprika and soybeans (over 75,000 hectares). In order to reduce additional land requirement and cost of production, intensive farming might be preferred. However this decision is dependent on the outcome of trade negotiations that Malawi Government might have with different countries. Again, in practice expansion of export markets is a huge challenge for poor countries and especially smallholder farmers. As noted by Jaffee & Henson (2005) and Kherallah *et al.* (2002), expansion of export markets is difficult due to protectionism, stringent technical and phytosanitary standards in different importing countries. For instance groundnuts has been frequently targeted for promotion by the Malawi Government before, however due to high incidence of aflatoxin levels in Malawian groundnuts (Matumba *et al.* 2015), market opportunities have been a challenge for smallholder farmers (Minde *et al.* 2008). Even if access to exports markets were guaranteed, other challenges may include lack of investments in storage and processing facilities for substitute crops, which at the moment are mostly non-existent except for tobacco itself.

5.8 Conclusion

This chapter has contributed to the debate on tobacco diversification in Malawi. The study concludes that tobacco would remain the most economic efficient crop in the foreseeable future, unless there is a major shift in crop markets and demand at global level. In case of tobacco curtail, no feasible alternatives emerged from the selected crops to completely substitute tobacco without loss of producer revenue and government forex base. However, in absence of tobacco, sugarcane, groundnuts and soybeans became highest contributors to producer revenue at 44.5%, 23.3% and 17.1%, respectively. As regards forex, sugarcane, groundnuts and cotton were the major sources at 47.4%, 29.13%, and 14.0%, respectively. As it is highly unlikely, that the agricultural sector would be able to cover up the forex earning deficit that may arise due to tobacco curtail, this should necessitate increased complementary investments in other non-agricultural sectors.

Chapter 6: Effect of Mitigation Support Mechanisms on Land Use, Soil Organic Carbon and Producer Revenue under Smallholder Agriculture in Malawi

Abstract

The common but differentiated responsibility, calls for all to participate in the reduction of greenhouse gases. This chapter analyses technological support mechanisms to promote smallholder farmers participation in mitigation. Subsidies were selectively applied to environmentally friendly technologies (EFTs) while taxes were also selectively applied to non-environmentally friendly technologies (NEFTs) to analyse the effect on land use, soil organic carbon abatement and producer revenues among smallholder farmers in Malawi.

Subsidies resulted into higher SOC abatements under actual cultivated areas but had lower total abatements on total arable land compared to taxes effect. This was because subsidies increased cultivated areas there by reducing the fallow areas, which sequester more soil organic carbon. Taxes had the opposite effect as it led to increased fallow areas and therefore higher soil organic carbon abatement. While taxes were more effective in SOC abatement, they had negative impact on producer revenues. A subsidy level of $50/ha on EFTs increased income levels by 8.4% while tax level of 50$/ha on NEFTs decreased farm incomes by 5.1%. These results may guide both country policy and global negotiations on how to support and optimise soil based mitigation under smallholder farmers.

Keywords: smallholder farmers, SOC abatement, technology adoption and producer revenues

6.1 Introduction

Article 10 of the Kyoto protocol (UN 1998) calls for the common but differentiated responsibility towards reduction of greenhouse gases, (Halvorssen 2007). Even though smallholder farmers are the majority of farmers in southern Africa and constitute up to 70% of the total population (Garrity *et al.* 2010), their role in mitigation is not well understood. This may be attributed to a number of factors. Firstly, most of the smallholder farmers belong to annex 2 countries under the Kyoto protocol, whose participation in climate mitigation is non-obligatory (Winkler *et al.* 2006). Secondly, the soil based mitigation options, unlike the energy and forestry sectors do not yet enjoy support mechanisms like Joint Implementation; Clean Development Mechanism; Emissions Trading; and Reducing Emissions from forest Deforestation and Degradation. This situation has resulted into some knowledge gaps on what kind and level of mitigation support mechanisms would be optimal for smallholder farmers or how such mitigation support mechanisms may affect technology adoption, SOC abatement and producer revenues.

6.2 Literature review

Interest for alternative carbon sinks include agriculture, which is estimated to contribute up to 13% of the total greenhouse gas emmissions but also represents 30% of total mitigation potential (Smith *et al.* 2008). According to Janzen (2004) and Sommer & Bossio (2014) soil organic carbon constitutes 80% of total greenhouse gases under soils. The known and potential mitigation options in agriculture include land use shifts i.e. from crops to fallow or to afforestation or bioenergy crops; improving nutrient application efficiency; reducing use of fossil fuels in heavy agricultural machinery and crop management practices among others (Lal 2004c; Smith *et al.* 2008).

However, smallholder farmers do not own heavy machinery like tractors and most of them apply insufficient inorganic fertilizers (GoM 2014b), which renders the two options non-viable for smallholder farmers participation in mitigation targets. The possibility of shifting from crops to fallow or bioenergy is low, as most smallholder farmers own small land sizes, averaging for instance 1ha per farming household in Malawi (GoM 2012a). As such, the most feasible soil based mitigation options under smallholder farmers are crop technologies like conservation agriculture and agroforestry (Lal 2004b; Smith *et al.* 2008)

Even though, soil based mitigation options are the most feasible for smallholder farmers, such mitigation options, unlike the energy and forestry sectors, do not yet enjoy support mechanisms like Joint Implementation, Clean Development Mechanism, Emissions Trading and Reducing Emissions from forest Deforestation and Degradation. This situation somehow disadvantages and may hinder smallholder farmer's participation in mitigation. Leaving out smallholder farmers in mitigation targets entails leaving out participation of the majority of the population in sub-Saharan Africa (70%) and in Malawi (80%). This would not only negate the principle of common but differentiated responsibility, but would also represent an opportunity lost to smallholder farmers, since soil based mitigation options are known to have co-benefits like improved soil health and increased crop productivity (Kamelarczyk 2009).

Not much has been studied regarding mitigation policy support mechanisms from smallholder farmers' perspective. As such their effect on technology adoption, SOC abatements, food security and producer revenues are not well known. The previous studies, have broadly looked into the status of SOC in different soil types (Falloon *et al.* 1998; Snapp 1998); relationship between crop technology adoption and SOC abatement levels (Chan *et al.* 2008; Ngwira *et al.* 2012); effect of SOC levels on crop productivity (Soler *et al.* 2011); and relationship between land use changes and SOC levels (Cambule 2013; Kamelarczyk 2009). As argued before, this chapter aims to add to the understanding on what kind and level of mitigation support mechanisms would be optimal for smallholder farmers and how such support mechanisms may affect technology adoption, SOC abatement and producer revenues of smallholder farmers, a case of Malawi.

6.3 Research questions

6.3.1 What kind and levels mitigation support mechanisms are optimal under smallholder farmers?

6.3.2 What would be the effect of such mitigation policy mechanisms on technology adoption, SOC abatement levels and producer revenues?

6.4 Methods

All data on national population, farming population, population growth, income levels, crops yield and SOC rates are sourced from MASM as described in chapter two. MASM is adjusted by activating the cost of or benefit of SOC abatement; the minimum food requirement to ensure that mitigation targets do not override food security goals and the period of study is 60 years. All crop and technology combinations which include maize, rice, cassava, soybeans, groundnuts, tobacco, paprika, cotton, sugarcane and sorghum under subsistence, conservation agriculture, *Falbedia albida*, optimal fertilisation, and intensive farming technologies were considered.

6.4.1 Mitigation policy support mechanisms

Mitigation policy support mechanisms were categorized as subsidies and taxes as highlighted in **Figure 6:1**. Subsidies were devised to incentivise farmers to adopt environmentally friendly technologies (EFTs) whereas taxes aimed to discourage farmers from adopting non-environmentally friendly technologies (NEFTs). Conservation farming and *Falbedia albida*, which sequester higher SOC levels, (Umar *et al.* 2013) represented environmentally friendly technologies, while subsistence, optimal fertilisation and intensive farming, which sequester lower SOC levels, (Lal 2004c) represented non-environmentally friendly technologies. Both subsidies and taxes may influence technology choices and shifts between EFTs and NEFTs. The business as usual (BAU), represented absence of mitigation support mechanism, which essentially depicted a situation where farmers adopt a technology without expectation of being subsided or taxed.

As there was no precedence in SOC mitigation support mechanisms, the study utilised theoretical subsidy and tax levels ranging from $0/ha to $50/ha of technology adopted. While many carbon projects or studies, such as (McCarl & Schneider 2001; Sauer *et al.* 2008) compensated farmers on per ton of carbon basis, i.e. $/ton of carbon sequestered, in trying not to disadvantage farmers from poor soils, the study compensated or penalised farmers per hectare of technology adopted i.e. $/ha. This approach may also simplify monitoring aspects in verifying SOC abatement per hectare to simple technology adoption in hectares.

Fallow area within the total arable land was included in the estimation of SOC sequestration. However fallow was not regarded as an active technology option for smallholder farmers as it does not involve technology investments but rather usually represents land abandonment due to low soil productivity. This is different from "improved fallow" where farmers invest in fallow to improve soil nutrition capacity, a trend which is not common among smallholder farmers. Even though fallow area was included in estimating SOC levels, to prevent farmers claiming compensation from idle or abandoned land, fallow area was excluded from mitigation support mechanisms.

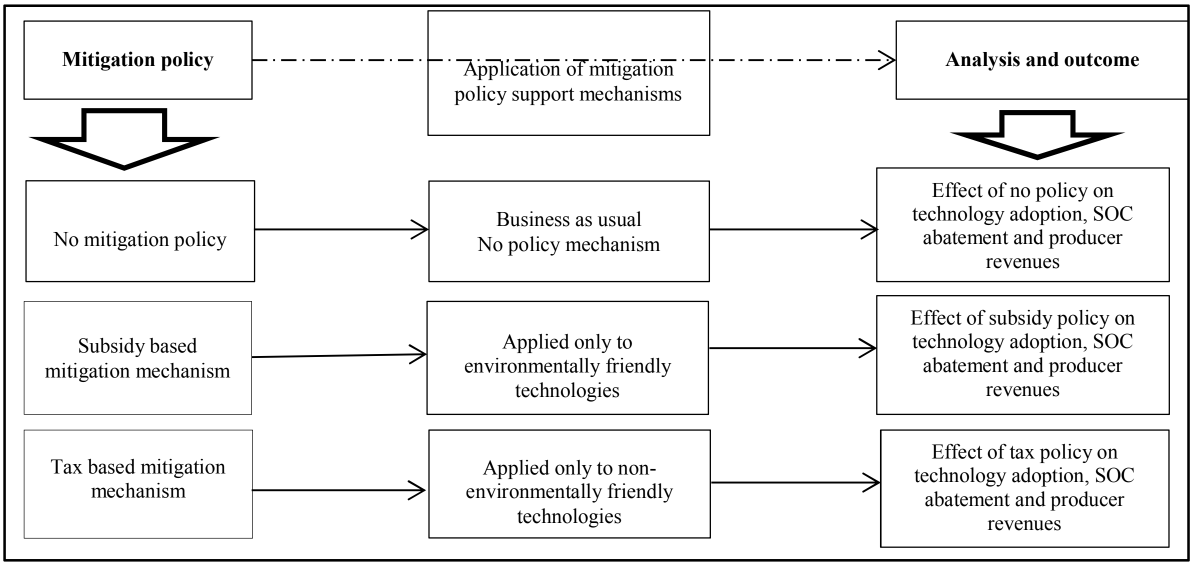


Figure 6:1. Diagrammatic outline of technology support mechanisms

6.4.2 SOC technical potential

The SOC technical potential ($T_{t,r}$) (**eq. 6:1**), represented the highest abatement that could be attained without any constraints other than the biophysical conditions and was estimated as a product of highest SOC sequestration rate ($\bar{g}_{j,m,t,r}$) and total available land ($\beta_{"land",t,r}$). The technical potential ($T_{t,r}$) does not depend on support mechanism (*d*) or level of support (*z*).

$$T_{t,r} = \sum_{j,m,} (\bar{g}_{j,m,t,r} \cdot \beta_{i,t,r}) \qquad \forall_{t,r} \qquad \textbf{(eq. 6:1)}$$

6.4.3 SOC economic potential

The SOC economic potential ($E_{t,r}$) **(eq. 6:2)**, represented the highest abatement that could be attained dependent on subsidy or taxes imposed ($/ha) and was estimated as a product of SOC sequestration rate ($\bar{g}_{j,m,t,r}$) and crop area ($L_{j,t,r,m}$) plus product of fallow sequestration rate ($\bar{g}_{"fallow","fallow",t,r}$) and fallow area ($\beta_{"land",t,r} - \sum_{j,t,r,m} L_{j,t,r,m}$):

$$E_{t,r} = \sum_{j,m} \left(\bar{g}_{j,m,t,r} \ . \ L_{j,t,r,m} \right) + \sum_{t,r} \left(\bar{g}_{\text{"fallow,"}fallow\text{"},t,r} \cdot \left(\beta_{\text{"}land\text{"},t,r} - \sum_{j,m} L_{j,t,r,m} \right) \right) \qquad \forall_{t,r} \qquad \textbf{(eq. 6:2)}$$

6.4.4 SOC social economic potential

As smallholder farmers strive with basic necessities like food security, the model was also designed to include a scenario where goals of mitigation did not override goals of food security. The social economic potential ($S_{t,r}$) was estimated like economic potential ($E_{t,r}$), subject to production of minimum food ($n_{t,r}$) (**eq. 6:3**) as previously already highlighted (**see chapter 2 section 2.4.9**)

$$n_{t,r} \geq 365\varphi \ . \ \Psi_{t,r} \qquad \forall_{t,r} \qquad \textbf{(eq. 6:3)}$$

6.5 Results

6.5.1 Cultivated and fallow areas

Cultivated areas and the subsequent fallow areas as percentage of total arable land are presented in **Figure 6:2. Figure 6:2-a** highlight the influence of subsidies and taxes on cultivated area while **Figure 6:2**-b shows respective changes in fallow area due to subsidies and taxes effect. Subsidy under social economic scenario increased crop area from 68% to 97%, whereas application of subsidy under economic scenarios also increased crop area from 64% to 94%. Taxing farmers for adopting NEFT technologies led to decreased crop areas from 68% to 31% under social economic scenario and from 64% to 21% under economic scenario. In general the increase in cultivated area (**Figure 6:2-a**) led to decrease in the fallow area (**Figure 6:2-b**) and vice versa. This relationship between cultivated and fallow areas has an impact on the total SOC abatement.

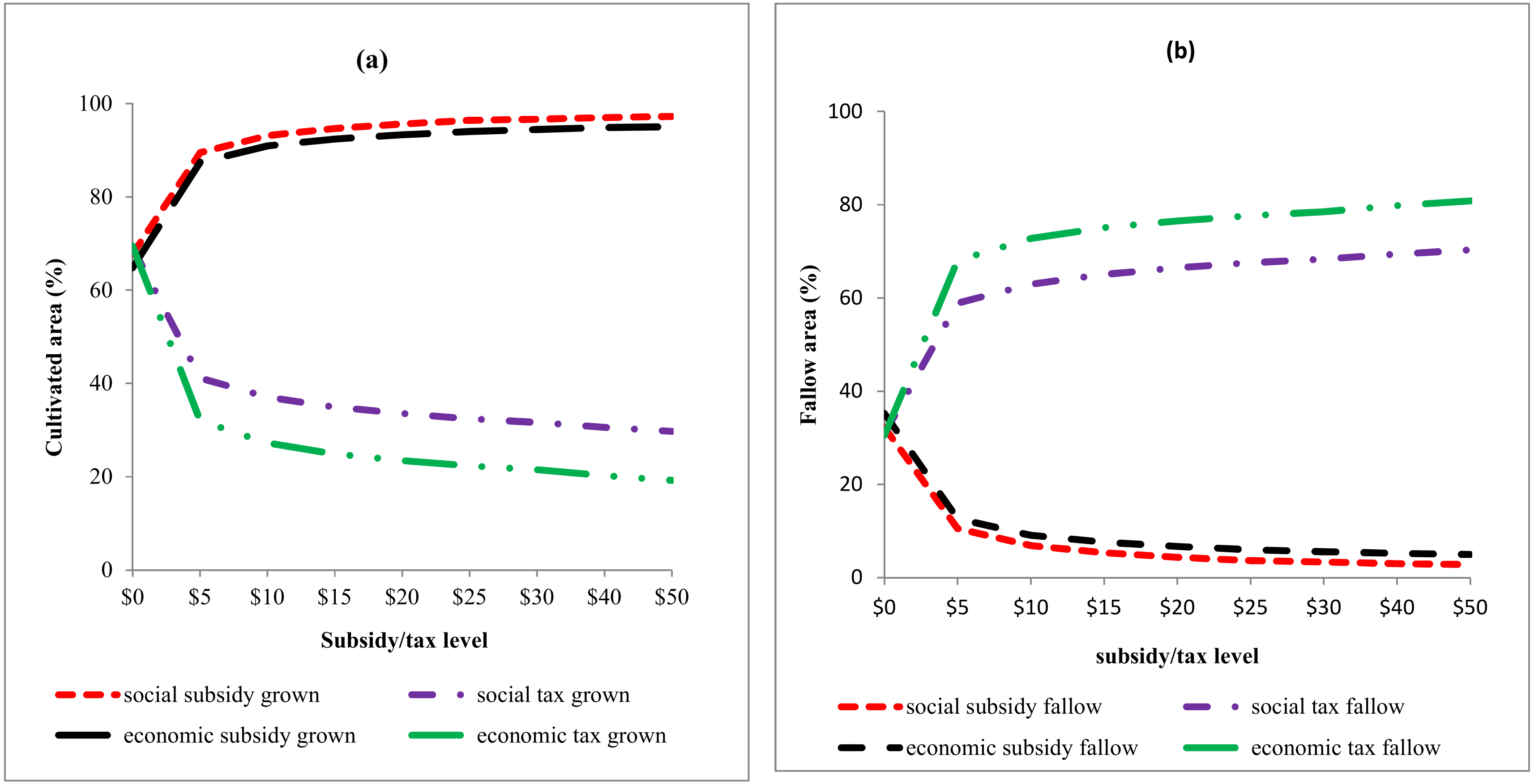


Figure 6:2. Effect of mitigation support mechanism on cultivated and fallow area levels.

(a) = cultivated areas (%). (b) = fallow area (%) in relation to total available arable land. Social subsidy grown = area under social economic scenarios when subsidies are implemented; social tax grown = area under social economic scenario when taxes are implemented; economic subsidy grown = area under economic scenario when subsidies are implemented; economic tax grown = area under economic scenarios when taxes are implemented.

6.5.2 Decadal cultivated areas

Decadal cultivated areas are presented in **Figure 6:3** . While there were variable trends within each decades and mitigation policy support mechanism, the general trend showed that increase in subsidies and decades resulted into highest crop area increase (**Figure 6:3-a)** and (**Figure 6:3-b**). Whereas increase in taxes and decades resulted in the lowest crop areas (**Figure 6:3-c**) and (**Figure 6:3-d**). Due to restriction on minimum food requirement highest crop areas were observed under subsidy use under social economic scenario with increased crop area from 64% ($0; 2nd decade) to 99% ($50; 7th decade). Taxes in general resulted into lower crop areas, taxes under social economic scenario had slightly higher crop areas from 66% ($0; 2nd decade) to 41% ($50; 2nd decade) when compared to 68%($0; 2nd decade) to 23% ($50; 2nd decade).

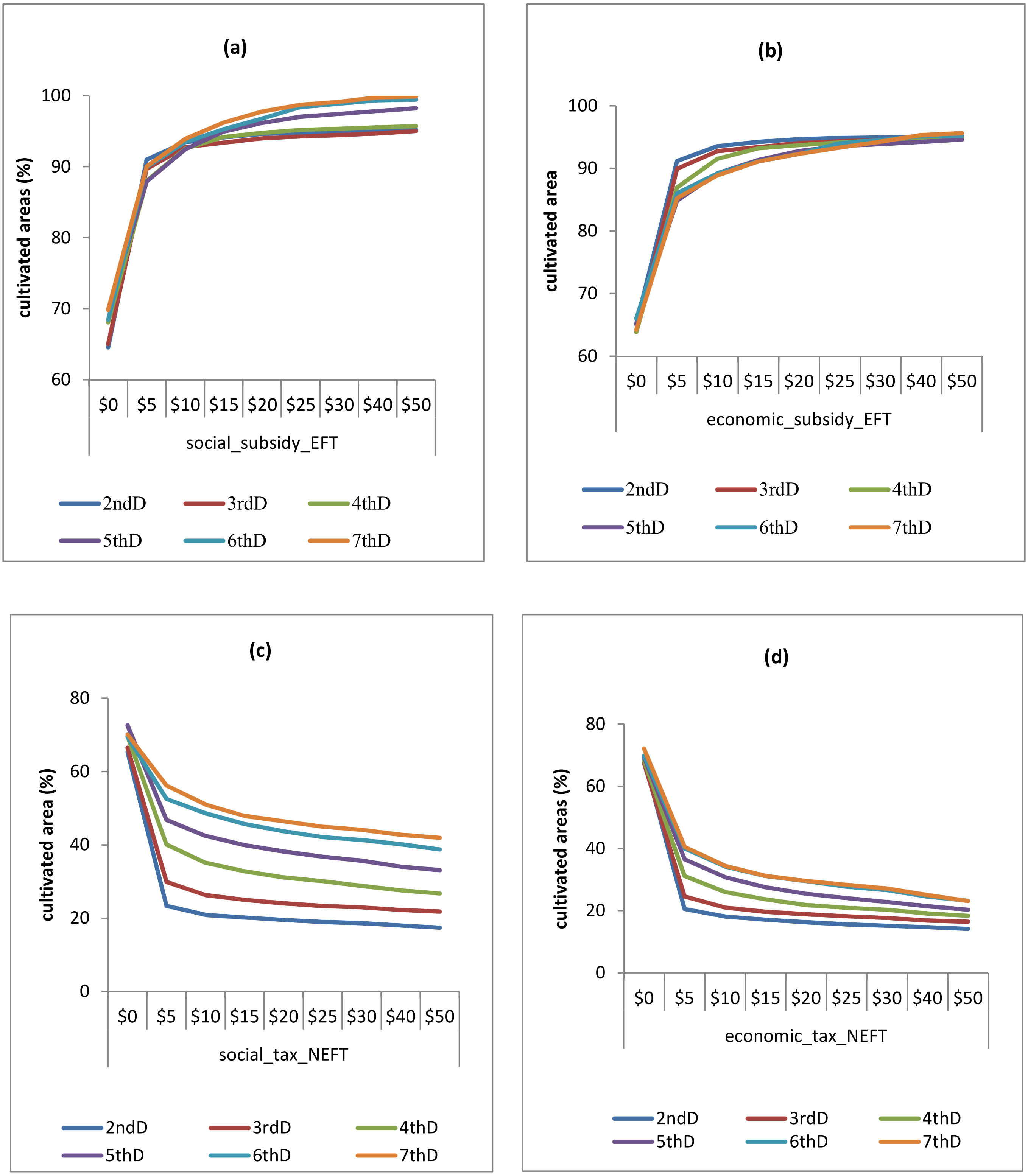


Figure 6:3. Effect of mitigation support mechanism on decadal cultivated areas

6.5.3 Decadal fallow areas

Decadal fallow areas are presented in **Figure 6:4**. As expected from the effect of mitigation mechanism on cultivated areas, subsidy under socio-economic had the least fallow areas (**Figure 6:4-a**) and taxes under economic had the highest fallow areas (**Figure 6:4-d**) Subsidies motivated farmers to use more land as it reduced cost of production and socio-economic scenarios also used more land to ensure production to meet minimum food requirement.

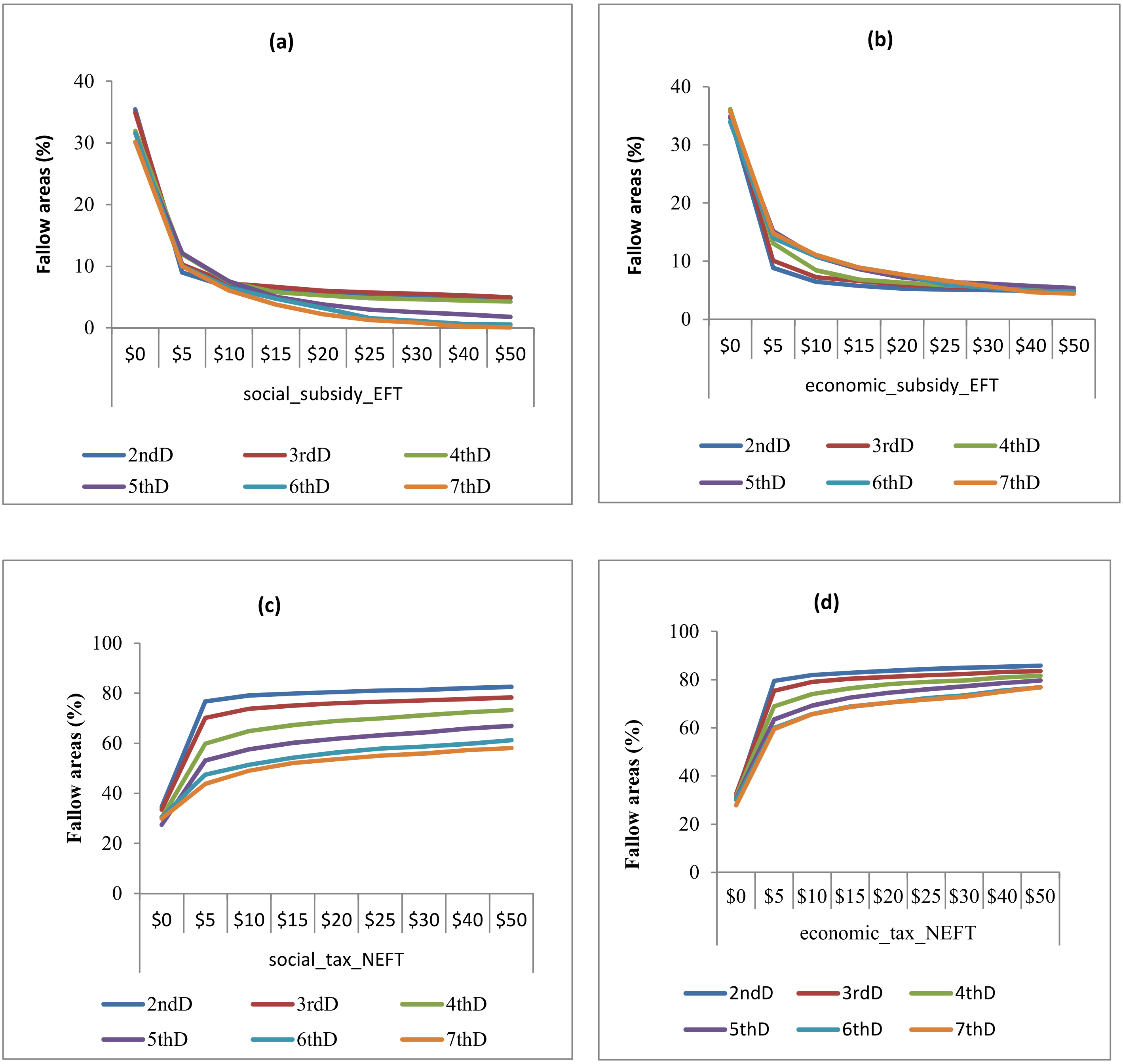


Figure 6:4. Effect of mitigation support mechanism on decadal fallow areas

6.5.4 Sequestration potential

The total mitigation potential was estimated as sum of SOC mitigation under cultivated areas (**Figure 6:5-a**) and subsequent fallow areas (**Figure 6:5-b**) in relation to technical potential. The total SOC abatement under crop grown areas and fallow areas are presented in (**Figure 6:5-c**). In **Figure 6:5-a**, subsidies led to higher adoption of EFTs which in turn sequestered more SOC when compared to grown area under taxes. The SOC abatements under subsidies ranged from 21% to 20% and 16% to 10% under social economic and economic scenarios respectively. While taxes SOC abatements ranged from 20% to 17% and 15% to 6% under social economic and economic scenarios respectively. Despite taxes having lower SOC abatements under crop grown areas, taxes had higher fallow areas which contributed higher to total SOC abatements (**Figure 6:5-b**). Overall, taxes resulted into more SOC abatement ranging from 30% to 39% under social tax and 28% to 40% under social economic scenarios, whereas subsidies SOC abatements ranged from 34% to 21% and 35% to 20% under social economic and economic scenarios respectively (**Figure 6:5**).

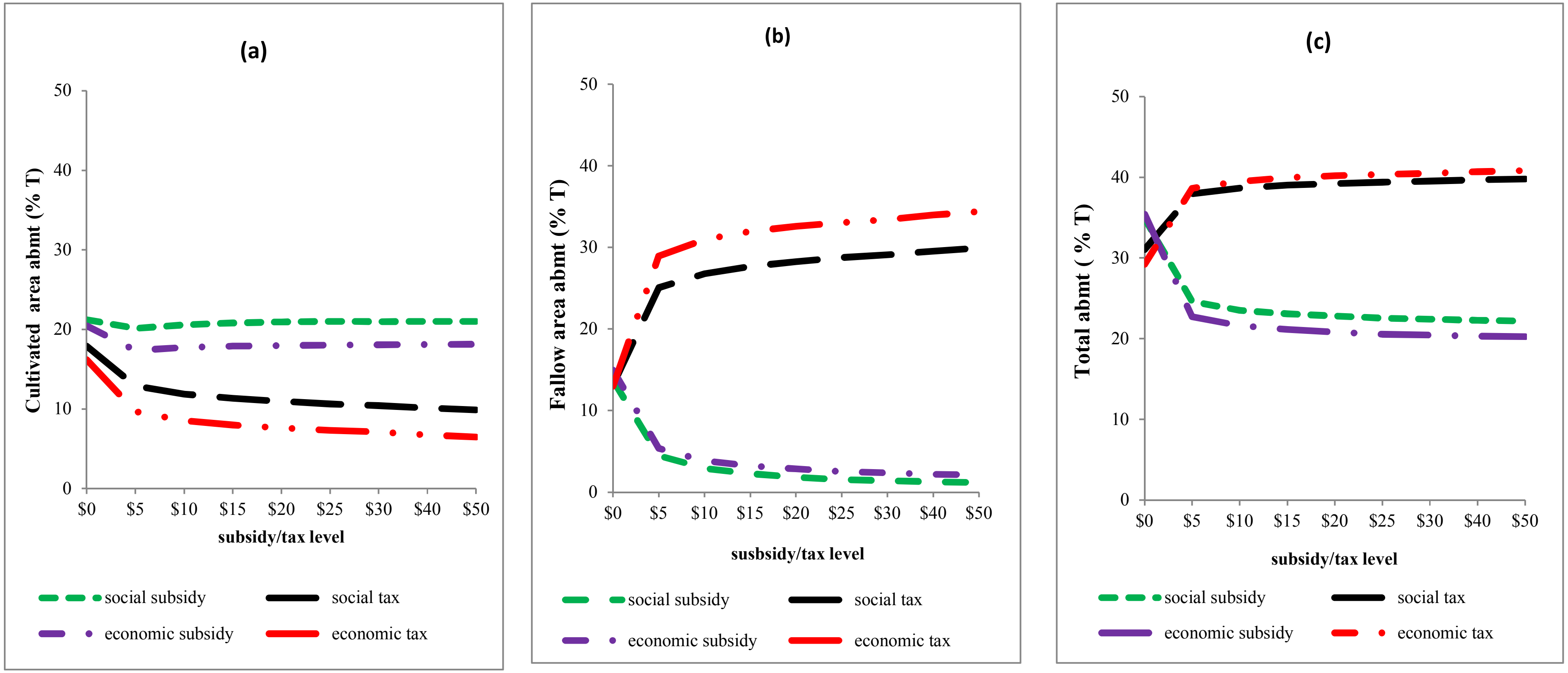


Figure 6:5. Effect of mitigation support mechanism on SOC sequestration potential.

(a) = abmt from grown area (%); (b) = abmt from fallow area (%) ;(c) = total abatement (%) in relation to SOC technical potential

6.5.5 Mitigation efficiency

Mitigation efficiency was estimated as levels of total SOC abatement and the cost of subsidies or taxes. **Figure 6:6** presents the efficiency of each mitigation policy mechanism. In the absence of mitigation policy mechanisms there was no cost of subsidies or taxes therefore the SOC abatement at $0 could not be estimated. Taxes had the highest mitigation efficiency but in both cases an increase in the level of mitigation policy mechanisms, resulted into reduced mitigation efficiency. Mitigation efficiency from taxes ranged from 9.1-2.3 tons/$ and 6.9-1.5 tons/$ under economic and socio-economic scenarios respectively, whereas mitigation efficiency from subsidies ranged from 1.9-0.7 tons/$ and 1.8 – 0.26 tons/$ under and economic and social economic scenarios, respectively.

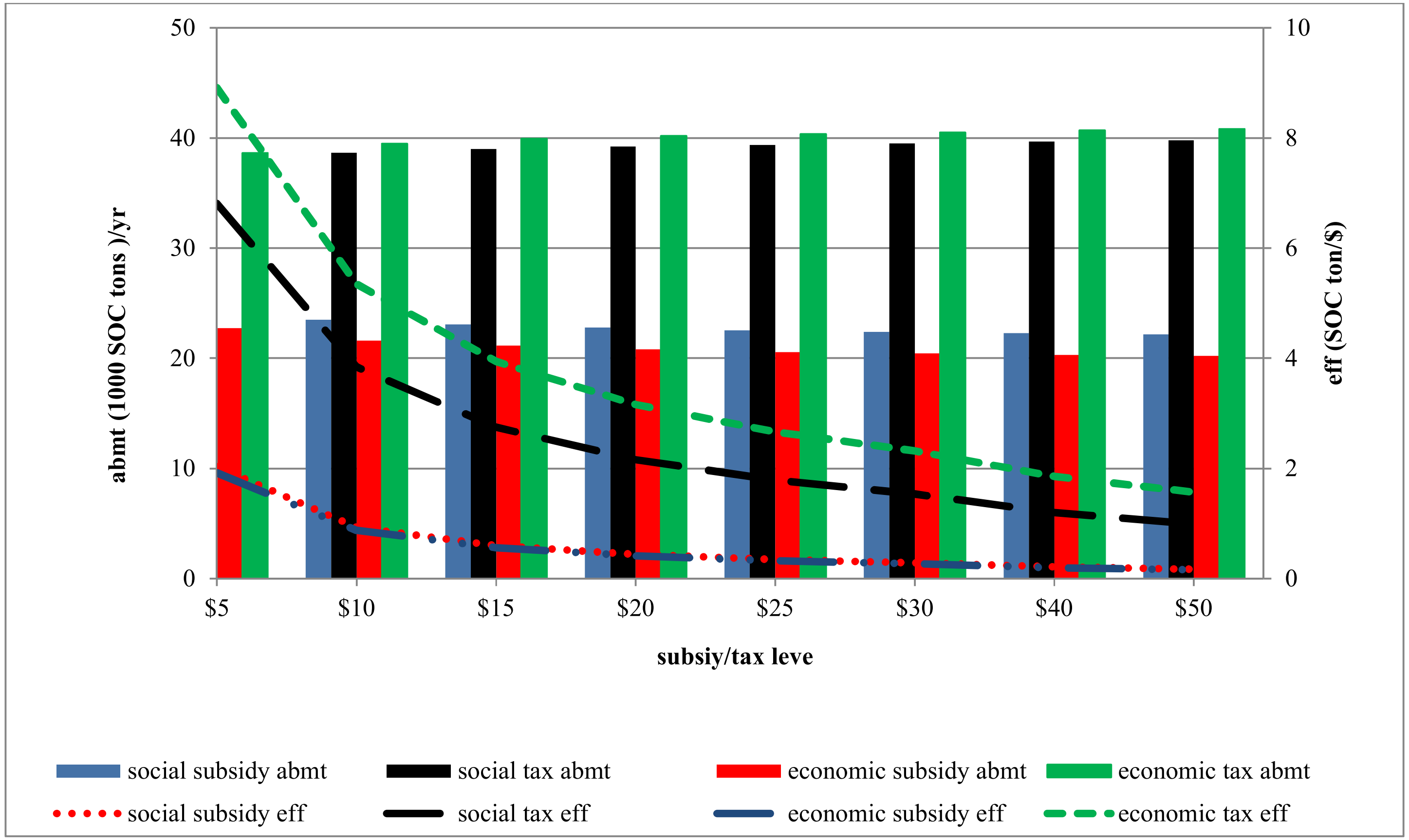


Figure 6:6. Efficiency of mitigation support mechanism

6.5.6 Changes in producer revenues

As shown in **Figure 6:7**, Technology subsidies under social economic scenarios increased producer revenue by 4.1% (subsidy; $5/ha) which increased further to 8.2% (subsidy ; $50/ha), whereas under economic scenarios subsidies increased farm revenue by 0.5% (subsidy ; $5/ha) which increased further to 2.2% (subsidy level of $50/ha). Taxes under social economic scenarios on the other hand decreased producer revenues by 0.4% (taxes; $5/ha) and decreased further to 1.8% (taxes; $50/ha), whereas under economic scenarios taxes decreased producer revenue by 3.9% (tax ; $5/ha) which decreased further to 5.4% (tax; $50/ha).

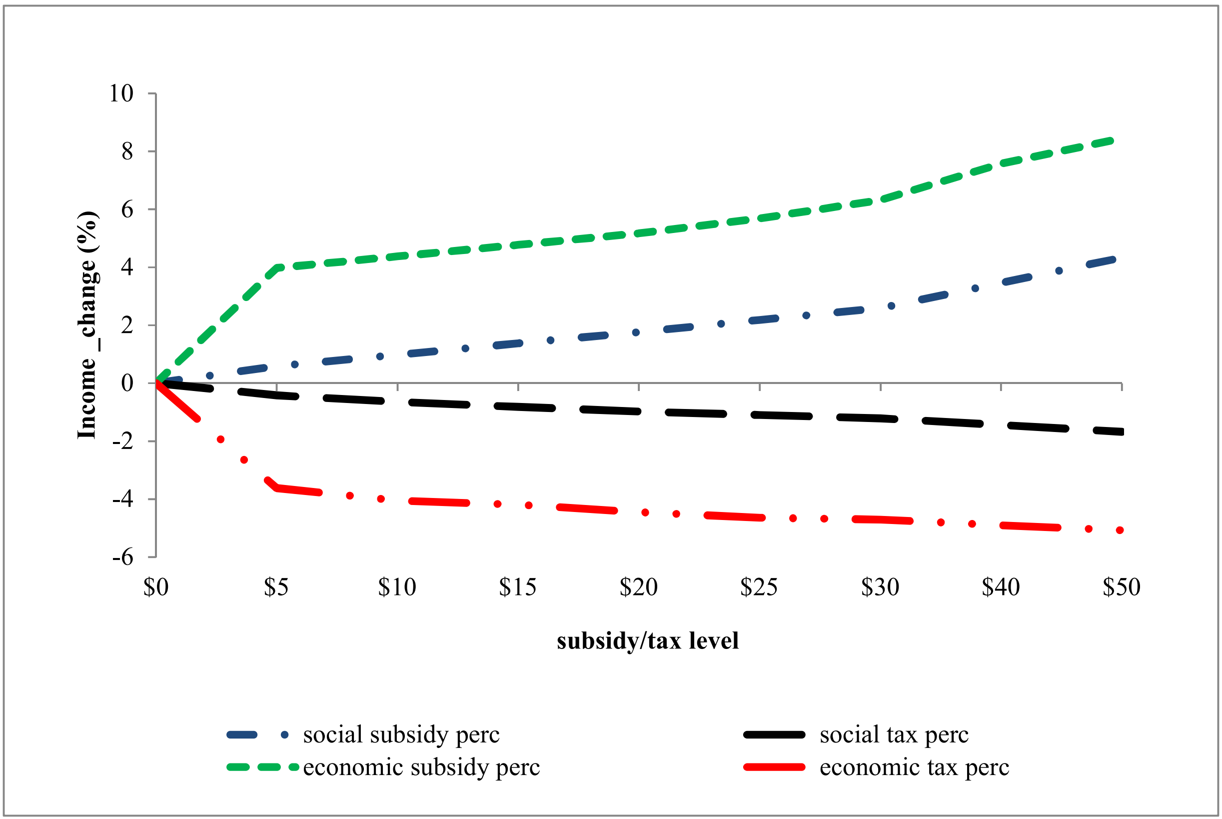


Figure 6:7. Effect of mitigation support mechanism on changes in producer revenues

6.6 Discussion

Increased subsidies resulted into increased cultivated areas while taxes resulted into decreased cultivated areas. This result could be explained in many ways: Firstly, under both subsidies and taxes, the EFTs (conservation agriculture and *Falbedia albida*) become more competitive and therefore farmers increase land to maximise income levels. Secondly, since the EFTs have low productivity i.e. yield per hectare when compared to NEFTs (optimal fertilisation or intensive farming), there was therefore need for farmers to increase crop area under EFTs in order to produce the equivalent minimum food as required by the model. Implementation of technology subsidies resulted into very high cultivated areas of 99% ($50/ha) in many decades. At this level of subsidy, ($50/ha) most of the arable land is nearly utilised, which means that increase in subsidies beyond this level would not lead to any further increase of technology adoption. The cost of technology subsidies would also be restricted by the availability of land that the smallholder farmers possess. However, if higher policy goals like poverty reduction, other than minimum food requirement were considered, more subsidies and less taxes would have been required to attain poverty eradication goals. The fact that cultivated area under social economic scenarios was higher than economic scenarios shows that food security goals would be affected if mitigation goals were priotised. This suggests that whenever mitigations targets are being sets under smallholder farmers, efforts must be made to avoid comprising food security.

The SOC abatement were analysed from 2 sources i.e. on the actual cultivated areas and then the subsequent fallow areas. Under cultivated areas, subsidies led to more adoption of EFTs resulting into higher SOC abatements than taxes. However the corresponding fallow areas for subsidy were much lower due to increase in cultivated areas and this resulted into taxes having higher total SOC abatements when compared to subsidies. While these findings agree with many previous studies where adoption of EFTs increased SOC abatement levels (Ngwira *et al.* 2012) and (Lal 2004b) such interpretation should be understood in regard to the actual cultivated areas and not necessarily the total available land. Otherwise, a few issues ought to be taken in consideration. For example, if conservation agriculture was compared with subsistence farming, then the total SOC abatement for EFTs would also be higher than NEFTs under both cultivated and fallow areas, since conservation agriculture is more productive in both yield and SOC abatement compared to subsistence farming. However if conservation agriculture was compared to intensive farming, conservation agriculture would require increased cultivated land to match total production under intensive farming, thereby decreasing the fallow areas. This then might result into lower SOC levels under conservation agriculture than intensive farming.

Taxes were more efficient than subsidies in both total SOC abatement and mitigation efficiency. In terms of total SOC abatement, increased mitigation support mechanisms led to increased total SOC abatement, however the mitigation efficiency decreased with increased mitigation mechanism levels. While efficiency (ton/$), estimated the optimal mitigation support mechanism, such estimation would be difficult in absence of actual policy mitigation targets in each sector, currently, such targets do not exist for non-annex 2 countries or for smallholder farmers. There was increase and decrease in producer revenues ranging from 2.6 to 8.2% and -1.8% to -5.2% under subsidy and taxes depending on social economic or economic scenario. The income levels under socio-economic scenarios were always lower than economic scenarios, this also arguments the fact that mitigation goals would conflict food security and poverty reduction goals.

6.7 Conclusion

Mitigation policy support mechanisms have potential to increase mitigation under smallholder farmers, however food security goals have to be guaranteed in setting such targets, as mere optimisation of mitigation targets under smallholder farmers would negatively affect attainment of food security goals. While taxes were overall more effective in SOC abatement than subsidies, the negative effect on producer revenues, renders taxes inappropriate under smallholder farmers. Subsidies have potential to increase adoption of environmental friendly technologies like conservation agriculture and *Falbedia albida* and consequently enhance mitigation potential on the actual cultivated area; however subsidies may also lead to increase in agricultural land and reduction of fallow areas which may reduce the total SOC abatement levels.

Chapter 7: : Summary and Conclusions

This thesis was motivated by a basic human necessity, to eradicate hunger and attain the right to food which currently eludes over a billion people globally, most of whom are farmers themselves and reside in sub-Saharan Africa. Malawi was selected as a vivid case study where the majority of the population are smallholder farmers and usually face hunger. A background to the Malawi agricultural sector was presented in chapter one to contextualise the hunger problem. The current and possible future scenarios that smallholder farmers may face were reviewed and formed the basis for research motivation. These challenges include among others reduced land holding sizes, low adoption of improved technologies, lack of crop diversification opportunities, inaccessibility to agricultural markets and climate change.

Having established the problem statement and the challenges thereof, specific research objectives were formulated to analyse, a) the effect of alternative food governance systems on hunger; b) the effect of climate change on crop productivity and the welfare of smallholder farmers; c) the effect of tobacco substitution on total welfare, producer revenue and forex base and, d) the effect of mitigation support mechanisms to smallholder farmers in Malawi. Using a biophysical economic approach the Malawi Agricultural Sector Model (MASM), was developed as a methodological approach to analyse the stated objectives. MASM replicated observed conditions in the base year satisfactorily.

Food governance has become a rising debate in international food trade that transcends arguments ranging from the rich heavily subsidised farmers in developed countries versus resource poor farmers in poor countries; the market protectionism versus free trade; and economic efficiency versus human rights and ethics. This thesis showed that in Malawi context, where producers are the majority of consumers, a food sovereign system would lead to higher food production and access but lower incomes in contrast with to the dependent system which provided higher incomes but insufficient access to food. The food sovereign system would easily be accepted by smallholder farmers who usually face hunger themselves and currently do not enjoy the benefits of external markets. However for policy makers, its implementation cannot be wholesome, to the entire agricultural sector, as this would demotivate big commercial farmers who provide employment to many Malawians and yet rely solely on external markets.

The thesis has also contributed to the understanding of climate impacts on crop yield and welfare of smallholder farmers. Alternative adaptation options which include novel technologies like conservation agriculture and *falbedia albida* have been suggested. Regardless of adaptation options, crop yields will be lower in future, however adopting other technologies other than subsistence farming allowed farmers to retain higher crop yields. While climate change will have a negative effect on smallholder farmers welfare, it was also found that farmers observed land use levels were non-optimal. Besides the effect of climate change, policy makers and stakeholders need to promote farmers in adopting optimal land use levels which can improve productivity and welfare of farmers.

Insights and options on the policy dilemma of tobacco production in Malawi have been provided. The high losses in government forex and tax base will provide guidelines to both anti and pro tobacco campaigners on the appropriate level of tobacco substitution and diversification, in order to reduce welfare losses. The study concludes that tobacco remains the most economic efficient crop in the foreseeable future, unless there are major shifts in crop markets and demand at global level. The most feasible crops to substitute tobacco are sugarcane, cotton and groundnuts. This recommendation though, highly depends on the type of markets that the government is able to negotiate with other countries. Whichever case, this thesis has provided market adjustments and land use levels for a wide range of crops that the government may choose from. However, due to external market expansion challenges, recovery options after the curtailing of tobacco must not be limited to the agricultural sector alone but involve other economic sectors in order to complement the agricultural sector.

Finally, the thesis considered technology support mechanisms that result in participation of smallholder farmers in mitigation targets without compromising food security. Environmentally friendly technologies like conservation agriculture and agroforestry improve soil fertility and crop productivity when compared to subsistence farming, but have lower yields when compared to intensive farming systems. Supporting farmers is necessary to promote the adoption of particular technologies, however, the level of support needs to be assessed and monitored to avoid unintended environmental consequences. For instance, conservation agriculture and agroforestry practices can result in reduced fallow areas and hence loss of SOC levels. Even though taxes are more efficient in SOC abatements, due to the negative effects they have on producer revenues, they should not be implemented under smallholder farmers.

In summary, to eradicate hunger among poor smallholder farmers who rely entirely on agricultural sector, certain policy protectionist mechanisms are required .i.e. the sovereign food governance. Climate change will affect crop productivity under all technologies in different regions differently; as such specific regional analyses are required for policy planning. The curtailing of tobacco requires high investments in external market for tobacco susbsitute crops, otherwise there would be negative effects for both farmers' livelihoods and the Malawian economy. With proper support levels, smallholder farmers may contribute effectively to mitigation targets without compromising on food security goals.

The methodology used for the study was appropriate. However, adjustments could be made to improve its robustness and applicability. For instance, while the study included a number of crops and crop technologies, other important technologies like legume-cereal intercropping could be added to MASM as an alternative technology option. Secondly, while currently the crop husbandry constitutes the major component of the Malawian agriculture sector, the inclusion of other agriculture sub-sectors, like fisheries and livestock into MASM may provide better insights for future adaptation options.

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