Potential Farm Planning Strategies for the Prevention of Modern Famines in Malawi Using Game Theory and Linear Programming Methods

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Authorization to Submit Thesis

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Abstract

This research presents plans for food self-sufficiency using linear programming and game theory techniques, both nationally and for twelve regions in Malawi for the purpose of decreasing the threat of modern famine for Malawian smallholder farmers under conditions of government assistance and no assistance. Comparisons between the weighted median land cultivated in the regions examined and the land recommended for cultivation from the linear programs were made to evaluate the recommendations of several institutions about the ratio of food crops to cash crops for smallholder farmers, as it was found several recommendations for food cultivation were too low to guarantee food security. This research also contains a discussion of famine mitigation and modern famine in the literature using the Web of Science and EBSCOHost databases.

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Dedication

This work is dedicated to my parents, who have been a source of unending support and encouragement throughout my education. I would also like to thank my many friends for their help and patience through this process, as well as the community at St. Augustine's for extending their home to me.

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Chapter 1

Introduction

1.1: Statement of Problem

Current estimates put the number of chronically hungry people in the world anywhere between one billion and 805 million (Conway, 2012: 329; FAO, 2014: 9). In an effort to decrease the population of the food insecure, the United Nations (UN) created a specific Millennium Development Goal (MDG) aimed at lessening the problem of hunger worldwide. Specifically, the goal states that the UN has a “target of halving the proportion of undernourished people by 2015” however the United Nations admits that this objective, while being close to completion, will not be attained worldwide at the target date (FAO, 2014: 9). Individual countries, like Malawi, have achieved their food security goals nationally, but the FAO still puts the number of hungry people in Malawi at roughly 22 percent of the population (FAO, 2014: 34). While this trend is encouraging, there is still room for improvement, which will likely be achieved through local actions involving agriculture as the economy of Malawi relies on a healthy agricultural sector. The FAO claims that the “agricultural sector [of Malawi] currently accounts for about 42 percent of GDP and 81 percent of export earnings” and much of this agriculture is done by smallholder farmers who “produce about 80 percent of Malawi’s food and 20 percent of its agricultural exports” (FAO, 2003). When considering the problem of food security, the smallholder farmers of Malawi must be a central part of the solution. There are several facets to the worldwide problem of food security, including the lack of available long-term data and research in most areas that are classified as food insecure, like Malawi. This research aims to add more analysis to this topic and to create a plan for both national and local agricultural strategies to increase food security using linear programming and game theory methods.

1.2: Proposed Study Area of Malawi

Food security is a global problem, but for the scope of this research, a national scale would be more appropriate as much of the data relating to food security is collected and given on a national scale. Another reason for focusing specifically on one nation is the opportunity to evaluate any government sponsored food security programs, like an agricultural subsidy, which would be available to the citizens of one country but might not be available in other nations within the same area. Given this constraint, this research will focus on the Republic of Malawi (See Figure 1, Appendix B). Malawi has had a sporadic history of man-made famine, especially in recent years. It is significant that these famines are mostly man-made, because they can be alleviated partly or entirely through changes in policy or planning strategies. Unlike many famines resulting solely from crop failures, droughts, or similar acts of God, man-made, or modern famines can result from the lack of response to a small shock to agricultural production. Adger (2006) underlines this point in his paper on vulnerability by saying: "While some famines can be triggered by extreme climate events, such as drought or flood, for example, vulnerability researchers have increasingly shown that famines and food insecurity are much more often caused by disease, war or other factors" (Sen, 1981; Swift, 1989; Bohle, et al., 1994; Blaikie, et al., 1994; Adger, 2006: 270). By linking Malawi's modern famines to ideas from the natural hazards literature, it can be seen as something easily preventable, so long as the appropriate plans are in place.

The years of food shortages in Malawi are occasionally followed by years of expanded government subsidies. For example, in the early 2000's President Mutharika unveiled a program where vouchers would be given "to smallholders to buy a small amount of fertilizer and seed so that they could replenish the soil nutrients, take advantage of improved seed varieties and at least achieve a livable crop from their tiny farms" (Tafirenyika, 2013: 9). Malawi, for a short time, saw an "increase [in] food production and [a promotion in] food security at the national level," which included grain surpluses that were exported to neighboring countries (Chibwana, 2010: 3; Tafirenyika, 2013: 9). This seems to give evidence to Sen's and Adger's claims that "[famines] and other crises occur when entitlements fail" (Adger, 2006: 271; Sen, 1971). The famines in Malawi do not solely result from the absence of a subsidy program, but years of food shortages always tend to follow a reduction in entitlements. In analyzing other periods of famine in Malawi, the pattern of policy causing famine can be clearly seen.

Chibwana, et al. (2010) has looked extensively at food shortages in Malawi since its independence and has discovered several reasons for past scarcities. In the late 1970's and early 1980's food security was threatened in Malawi by "the outbreak of civil war in neighbouring Mozambique (which led to an influx of refugees)" as well as several government policies which were not as helpful as originally intended, including one which kept "maze prices […] low to reduce the price of food and encourage production of cash crops for export" (Chibwana, 2010: 5). This policy backfired as "[by] the mid-1980s, it was apparent that most Malawian households could not afford to buy the maize that filled ADMARC's [Agricultural Development and Marketing Corporation] warehouses," which led to "a food crisis in 1987, as a result of declining per capita maize production and the inability of ADMARC to purchase maize" (Chibwana, 2010: 6). Maize is often seen as the key to food security in Malawi as the diet of many Malawians consists of roughly 75 percent maize (Menon, 2007: 1). This reliance on maize as a main diet staple may also be the case in the surrounding countries, but the focus of this study is Malawi specifically.

Malawi continued to struggle in the 1990's when the World Bank began making policy recommendations in an attempt to alleviate Malawi's poverty problem. Malawi adopted an "Agricultural Sector Adjustment Program" which removed the previous restriction "that barred smallholder farmers from growing burley tobacco and other commercial crops" (Chibwana, 2010: 6). This was done to "remedy the policy bias against the smallholder" farmer, and under this new program "[smallholder] farmers were encouraged to produce exportable, high-value cash crops" (Chibwana, 2010: 6). In addition, the World Bank re-introduced the policy where "[maize] prices were deliberately kept low to discourage its production" and "maize fertilizer subsidies were discontinued" (Chibwana, 2010: 6). These policies, along with other factors like refugee influx and "a freeze in Western non-humanitarian aid" led to "the worsening of poverty" in Malawi (Chibwana, 2010: 6-7). By removing the fertilizer subsidies and making cash crops available to smallholder farmers, as well as keeping the price of Maize low, "cash crops displaced maize" leading to subsequent food shortages (Chibwana, 2010: 7). The discontinuation of the fertilizer subsidies has been seen by many as an "ill-fated effort" to improve the economy on the part of the World Bank (Lele, 1990: 1211).

The re-introduction of new subsidies – like the Starter Pack Scheme (SPS) – saw growth in both "per capita GDP, per capita agricultural GDP, and per capita smallholder agricultural GDP," although this growth was also partly due to the "increase in production of root crops […] and other cash crops" (Chibwana, 2010: 7). Using measures like per capita GDP is sometimes questionable, as it is not always the best measure of progress or development. For one, per capita GDP distributes income across all people, not solely the employed population, and isn't representative of the actual incomes of the working population of the country. Per capita GDP also does not address issues of equity or inequality in the society, which would be more telling for measures of development. Using measures of per capita GDP may not be ideal, however research is sometimes forced to use measures such as these as they are the only data available to describe the situation.

The SPS subsidy proved to be helpful, however, because as it was "drastically scaled down in 2001" to become the Targeted Inputs Program (TIP) "smallholder maize production declined sharply," though the weather partly contributed to this decline in production (Chibwana, 2010: 7). Both programs were blamed for "perpetuating widespread dependency on maize" and a continuation of poverty for many smallholder farmers, however the "small provision for tobacco fertilizer and pesticides for cotton" – or help for producing cash crops that were also included in the subsidy – were not mentioned (Chibwana, 2010: 7-8). The TIP subsidy ended in 2005 in favor of the Farm Input Subsidy Program (FISP), which is the current government subsidy offered to smallholder farmers in Malawi (Pauw and Thurlow, 2014: 1). Over the years, the FISP package has been slowly paired down, especially the amount of fertilizer awarded to recipients. Still, the farmers who receive the subsidy generally see an increase in maize yields "from about 1.3 mt [under the TIP subsidy] to an average of 2.7 mt [under the FISP subsidy] per [hectare]" (Pauw and Thurlow, 2014: 1).

While this current trend is a positive one, back in 2002 the country was in the throes of "the worst [famine] in Malawi's recorded history" (Devereux, 2002: 70). The 2002 famine was initially caused by “abnormal rainfall” and “localised flooding,” but was exacerbated by the sale of the government’s Strategic Grain Reserve (SGR), which prevented the government from getting maize to the deficit prone areas, as well as the lack of response from international and aid agencies (Devereux, 2002: 71-7; Menon, 2007). The sale of the SGR was especially damaging due to transportation difficulties making international support slow to arrive, further restricting food availability within the country (Philips, 2007: 1; Devereux, 2002; Menon, 2007). The famine in 2002 in Malawi was seen as a modern famine, despite the initial weather shock provocation, because a similar famine in 1991 resulted in agricultural yields that were “less than half the 2001 harvest” but not nearly so bad in terms of loss of life (Devereux, 2002: 76). Factors which contributed to the worsening of the 2001 famine are generally seen as “political and institutional issues, […] the absence of safety nets, and strained relations between the government of Malawi and donors” as well as an inability to import maize stocks as “the floods that caused harvest failures also washed away feeder roads, bridges and railway lines, disrupting the movement of food both into and inside Malawi” (Philips, 2007: 1; Devereux, 2002: 75). Additionally, in the famine of 1991, “ADMARC [now the SGR] retained adequate supplies of cereals in its markets at affordable prices” which helped improve food access to the affected districts, something which became an issue in 2002 as “access to food was restricted for some because grain did not reach the most rural areas, and prices soared, making white maize, the staple food, too expensive for many to buy” thus exacerbating the initial production shock (Devereux, 2002: 74; Philips, 2007: 1).

1.3: Notable Policy Recommendations

Due to the famine in 2002 and the government's recent reinstatement of agricultural subsidies, a number of agencies have descended on Malawi in the hopes of examining the recent food security issues in order to describe the current situation and recommend strategies to improve the state of Malawian food security. A report by the Global Facility for Disaster Reduction and Recovery (GFDRR), gives an overview to the current state of food security and smallholder agriculture in Malawi:

> "Over 50 percent of the population lives below the poverty line and one in five people is chronically food insecure. Rainfed subsistence agriculture is the main livelihood for 85 percent of the population, leaving them highly vulnerable to weather shocks such as erratic rainfall that can cause flooding in the south, and periodic droughts that affect the entire country" (GFDRR, 2011: 2).

Malawi is not unique to rely on rainfed subsistence agriculture in Sub-Saharan Africa, as a majority of agriculture is rainfed within the region (World Bank, 2015). Most reports on Malawi begin in a similar way as the GFDRR study, with an array of facts believed to help contribute to the current state of food security in the country. GFDRR's claim was that "[food] security in Malawi is largely determined by the availability of maize – the staple crop" (GFDRR, 2011: 14). The United Nations Development Program's (UNDP) paper about the famine in Malawi also cited maize as closely tied to the country's food security, as "90 percent of the population consists of subsistence farmers, who rely on the food they grow themselves for survival" and that maize counts "for about three quarters of calorie consumption for the population" (Trócaire, 2005; ActionAid International, 2006; Menon, 2007: 1). Other reports, like Future Agriculture's working paper, have pointed to the size of farm plots in Malawi being a significant factor by including the figure that "55 percent of smallholder farmers have less than 1 hectare of cultivatable land" (Government of Malawi, 2002; Chirwa and Matita, 2012: 3). Still others point to the crops farmers are growing as a possible factor: "[most] smallholder farming is […focused] on producing food staples such as maize" (Chirwa and Matita, 2012: 3). Generally the introductions to these studies include a wealth of information related to the type of study they are conducting, but little about other possible contributory factors, or reference other studies being done, with the exception of the International Food Policy Research Institute's (IFPRI) assessment.

Many of these reports expressed concern about the current food security situation, including the Malawi Vulnerability Assessment Committee's (MVAC) annual report in 2013 that claimed "21 districts […] will face food deficits ranging from 2 to 5 months" (Ministry of Economic Planning and Development (MEPD), 2013: 1). The MVAC report continues to explain that these food deficits will result in a "number of people who will not be able to meet their annual food requirement during the 2013/14 consumption period […roughly] 9.5% of the total population" (MEPD, 2013: 2). These food deficit concerns were echoed by other reports, like the IFPRI assessment which looked at the effectiveness of the subsidy program currently being offered in Malawi – the Farm Input Subsidy Program (FISP). The report agreed with the MVAC food security findings, but was encouraging about the FISP subsidy's role in increasing the country's maize yield: "prior to FISP, the country only produced surplus maize when subsidy programs were universally targeted" (Harrington, 2008; Pauw and Thurlow, 2014: 1). This claim was an echo of MVAC's report which also touted the role of FISP in agricultural production: "Malawi has produced maize surpluses at [the] national level for the past seven consecutive years. These surpluses can be largely attributed to the FISP programme" (MEPD, 2013: 2). This seems contradictory considering the projected food deficits in the rest of the report, but IFPRI explains that FISP and the current projections may be tied together as they claim “some are blaming current food deficits on the fact that FISP has been downscaled in a time of high fertilizer costs” (Pauw and Thurlow, 2014: 4). The success of subsidies in Malawi is scrutinized quite heavily because their reestablishment was carried out “against expert advice,” but FISP has proven successful in increasing maize yields (Pauw and Thurlow, 2014: 1; Shiverly and Ricker-Gilbert, 2013).

Recommendations from these papers are wide-ranging, including both broad and specific suggestions. GPRI’s suggestion was to promote the planting of legumes, which can benefit farmers nutritionally, as well as “[returning] nitrogen to the soil, which can lessen the need for chemical inputs and further reduce the need to subsidize fertilizer” (Shiverly and Ricker-Gilbert, 2013: 6). The GDFRR’s conclusion – that “[continued] reliance on the maize crop will restrict livelihood options for millions and exacerbate food insecurity over the long term” – was quite radical, considering how integral maize is to the Malawian diet, but worth examining (GFDRR, 2011: 8). The UNDP report was less revolutionary, as it called for promoting “crop diversification, thereby moving away from over-dependence on maize and boosting smallholder incomes” (Menon, 2007: 11). This recommendation comes from a concern explained in the report of weak maize markets which allow for “sudden severe price hikes [to] keep food out of the hands of the poor during the hungry season” (Menon, 2007: 10). The UNDP believes that “inter-seasonal food price fluctuations” are largely to blame, which is a fair claim as the Institute of Development Studies (IDS) discovered that “[in] most years, retail maize prices in Malawi are lowest after harvest in June/July, and rise by 50-100 per cent over the next six months, peaking during the lean period between December and

February" (Menon, 2007: 10; Devereux, 2002: 75). This can help explain why there is a national food surplus, but a portion of the population will experience food deficits during parts of the year.

The incredible fluctuation in maize prices during the year is likely one reason why several reports have pointed to food self-sufficiency as the recommended strategy for smallholder farmers. Food self-sufficiency, or food autarky, and its effect on the health of farmers has been studied in Rwanda, but not in Malawi. A study by Muller (2001) found that health in rural Rwandan households was related to what crops were being grown by the household (Muller, 2001). If a household grew mostly beans their level of health was generally high, but if the household grew mostly bananas for alcohol production their level of health was generally lower (Muller, 2001). Muller believed that household health would improve if the farmers were educated about the negative health effects of beer crops and if there were improved food markets or incentives to grow crops aside from those used in alcohol production. Muller (2009) again examined Rwandan peasants and the effect of partial autarky on health (Muller, 2009). Here again it was found that households that primarily cultivated food crops like beans and sweet potatoes had better levels of health than households who produced food for the production of alcohol (Muller, 2009). He once more concluded that "for the management of health and nutritional care, one should devote more attention to the agricultural activities and crop selection of peasants" (Muller, 2009).

IFPRI's study hinted at an autarkic strategy when it concluded that research should "continue exploring outcomes under policy alternatives, including those that are less prone to weather or price risks," as well as MVAC's recommendation that the "[government] and its partners should explore a range of interventions varying from cash-based to food-based intervention," specifically stating "[interventions] that build people's resilience should be given priority" (Pauw and Thurlow, 2014: 4; MEPD, 2013: 4). The recommendation supplied by Future Agricultures split the difference by championing a position by the National Smallholder Farmers' Association of Malawi (NASFAM), an organization specific to smallholders, which suggests that "those who usually cultivate less than 1 hectare of land, [should be] producing 60 percent food and 40 percent cash crops" (Chirwa and Matita, 2012: 3). This recommendation is likely to be impactful in Malawi as NASFAM is billed as being "the largest independent, smallholder-owned membership organization in Malawi," though it claims just "over one hundred thousand members" in a country with roughly twelve million farmers (NASFAM, 2015).

1.4: Research Queries and Contributions

The work of this study will be to address some of the concerns brought to light about Malawian food security through some of the previous reports. Very little study has been done in Malawi relating to crop planning strategies as a reduction for food insecurity, especially those using game theory and linear programming techniques. Several questions will be used in directing this research, with the goal that any resulting answers will add to the literature and be helpful in determining a strategy to mitigate future food security issues in Malawi. It is expected that several contributions will be made from this research. For academics, the goal is that this research will strengthen the link between linear programming and crop planning strategies, as this technique is seldom used for this purpose despite its effectiveness. It is also a goal that researchers examining famine will include instances of modern famines in their research, and not just focus on famines resulting from droughts, as well as a discussion of possible mitigation strategies for instances of famine, regardless of type. For institutions, policy makers, or aid agencies, the aim is that the presentation of linear programming as a tool for creating a crop planning strategy for the prevention of famine in Malawi will allow for its use in other regions or areas affected by a similar type of food insecurity to increase the food self-sufficiency of a region. It is also an intention that this research will one day be tested in a real-world setting to determine the true effectiveness of this plan.

First, to address the policy recommendations relating to decreasing vulnerability came the question: How can crop planning strategies be seen as a form of mitigation for a potential famine hazard? To adequately address this question, the topic of famine in the hazards literature will be discussed. This will give a brief overview of the work already done, if any, as well as highlight any avenues for future work within the field.

Second, to address the recommendations about food self-sufficiency and whether maize is the reason for reduced food security or if planting other food crops would be better: Can a mix of different staple crops be determined using game theory and linear programming to give a somewhat diversified diet for smallholder farmers using five of the most common food crops produced in Malawi? The aim of this question is to attain a planning strategy which would allow Malawian farmers to have no food deficits at any time during the year. The decision to use the most common staple crops was made as smallholder farmers would already have access to the resources to grow those crops, the crops selected already grow in the area, and the farmers would already know how to grow those crops. The linear program would present an optimal plan, and game theory would be used to see how often that plan should be implemented, given a certain set of constraints. The resulting plan will help smallholder farmers attain food security through food self-sufficiency.

The third research question was meant to address the specific recommendation from NASFAM and Future Agricultures about a split of sixty percent of land cultivated for food crops and forty percent for cash crops: Can an ideal percentage of land devoted to cash crops be determined to protect against potential hunger as well as guarantee an income for farmers in Malawi? This was chosen due to the specificity of the recommendation, and that the recommendation is coming from NASFAM. This will be answered by taking the plan resulting from the previous question about what quantities of which crops would result in a plan with greater food security, and comparing the total hectares needed to cultivate the plan with the total number of hectares in an average smallholder farmer's plot. The goal of this research will be to test the figure from NASFAM to see if they are supporting an appropriate plan, and if not, to suggest an alternate plan for endorsement.

One final question arose in order to address specific regional issues in an attempt to build on the previous work and adapt the plan for a greater number of situations: Can a discussion of regional issues help to adapt the national planning strategy for specific regions in Malawi? The climate differs throughout the country, and while having a national planning strategy is a good first step towards reducing food insecurity, it would be helpful to note any regional issues which may impact its effectiveness. The goal of this discussion is to address possible weather related problems so that future research can adapt the plan and tailor it to a specific area to further increase food security in Malawi.

1.5: Thesis Structure

Six sections and two appendices compose this thesis. This section has presented an overview of the general problem, as well as made a case for the selection of the study area.

The next section will contain a presentation of the literature concerning modern famine, vulnerability, game theory, and climate as it relates to the research questions and to the study area of Malawi. Section three will explain the data and being used in this research. The fourth section will present and discuss the methods used in this research. The results of this study as they relate to the research questions from the first section are presented in section five. The final section will present concluding remarks from this study and make a case for future work. Appendix A contains tables relating to the research presented here, and Appendix B contains several maps of the study area.

Chapter 2

Literature Review

2.1: Modern Famine and the Entitlement Approach

To begin, modern famine must be differentiated from traditional famine. Traditional famines, according to Sen, result from a decline in the available food, whereas modern famines result from an inability to attain adequate food (Sen, 1981). Turner (2003) shares Sen's definition of modern famine in his paper on vulnerability analysis: "modern famines follow not from insufficient food stocks but from the inability of social units to command food access through legal and customary means" (Turner, 2003: 8075; Drèze and Sen, 1989). In the essay *Poverty and Famines*, not much time is spent defining what is meant by a famine specifically, as Sen explains that "[while] there is quite a literature on how to 'define' famines, one can very often diagnose it – like a flood or a fire – even without being armed with a precise definition" (Sen, 1981: 39-40). The World Food Program and Conway define famine in terms of starvation: "*Starvation* is an extreme form of these conditions [malnutrition and undernourishment], characterized by a "state of exhaustion of the body caused by lack of food." When starvation is accompanied by increasing mortality on an epidemic scale, we usually describe it as a *famine*" (Conway, 2012: 22; WFP, 2010).

The aim of Sen's essay was not to define famine, but instead to discuss a theory on their origin which was previously ignored by the literature, or erroneously explained under the category of "food availability decline" (Sen, 1981). He does this through his analytical framework in examining famines, called the "entitlement approach" (Sen, 1981). Sen explains his approach as follows:

> "The entitlement approach to starvation and famines concentrates on the ability of people to command food through the legal means available in the society, including the use of production possibilities, trade opportunities, entitlements *vis-à-vis* the state, and other methods of acquiring food" (Sen, 1981: 45).

The entitlement approach is useful in situations of modern famine, because it looks at a multitude of methods available to obtain food during a time of famine instead of focusing on the total amount of food available in a particular area, which may or may not be a factor in the hunger of a particular area. As Sen explains, "[starvation] is the characteristic of some people not *having* enough food to eat. It is not the characteristic of there *being* not enough food to eat" (Sen, 1981: 1). Sen's use of starvation is more explanatory as to the cause of starvation with respect to the food supply, whereas the World Food Program's definition was more specific to how people in a particular area would experience starvation mortality during a famine. This sentiment is continued as Sen considers food supply: "[food] supply statements say things about a commodity (or a group of commodities) considered on its own. Starvation statements are about the *relationship* of persons to the commodity (or that commodity group)" (Sen, 1981: 1; Sen, 1976b; Sen, 1979a).

A person's relationship to a commodity can differ based on factors like employment. For example, subsistence farmers have access to food based on what they grow, whereas workers rely on the exchange of their wages for food, and another group "may produce a commodity that is both directly consumed and exchanged for some other food" such as fishermen or pastoralists (Sen, 1981: 51). These relationships each contain different risks during times of shortage and famine. For pastoralists or fishermen, risks are possible from both parts of the relationship, either in the supply of food they produce, or from a collapse in their value which limits what food they can access by trade, making "both direct entitlement failure and trade entitlement failure" possible for this sector (Sen, 1981: 51). For wage earners, risks during times of food price spikes – events which often occur during times of shortage and famine – are very high when compared with subsistence farmers: "a fixed money wage may offer no security at all in a situation of sharply varying food prices (even when employment is guaranteed). In contrast, a share of the food output does have some security advantage in terms of exchange entitlement" (Sen, 1981: 5). Cash croppers, while farmers, are also at risk because of their relationship to their commodity. Sen explains this by looking at both cash croppers and pastoralists:

> "Compared with the farmer or the pastoralist who lives on what he grows and is thus vulnerable only to variations of his own output (arising from climatic considerations and other influences), the grower of cash crops, or the pastoralist heavily dependent on selling animal products, is vulnerable both to output fluctuations and to shifts in marketability of commodities and in exchange rates" (Sen, 1981: 126).

This goes beyond the idea of a decline in the total amount of food available and looks at how groups of people are able to get food when they aren't solely producing food products by incorporating food prices and market forces.

The entitlement approach discusses two different ideas behind identifying who "the poor" are in a society by looking at sets of 'basic needs' or 'consumption baskets': "[one method] is simply to check the set of people whose actual consumption baskets happen to leave some basic need unsatisfied. This we may call the 'direct method', and it does not involve the use of any income notion," whereas the second method is based on income measures (Sen, 1981: 26). Sen weighs the merits of each method, but eventually declares that "the direct method is superior to the income method, since the former is not based on particular assumptions of consumption behavior which may or may not be accurate. Indeed, it could be argued that *only* in the absence of direct information regarding the satisfaction of the specified needs can there be a case for bringing in the intermediary of income" (Sen, 1981: 26; Rowntree, 1901). Later, Sen clarifies that the direct method examines "those whose actual consumption fails to meet the accepted conventions of minimum needs" whereas the income method looks at "those who do not have the ability to meet these needs within the behavioural constraints of the community" (Sen, 1981: 28). The direct method will be more appropriate for use in this particular study, as it will examine subsistence farmers and focus on self-sufficiency in an attempt to meet the minimum nutritional needs of a household.

The idea of minimum needs can be expressed in terms of either commodities or characteristics. Issues tend to arise from translating characteristic needs into commodities: "[if] characteristics could be obtained from only one commodity and no others, then it would be easy to translate the characteristics needs into commodity needs. But this is very often not the case, so that characteristics requirements do not specify commodity requirements. While calories are necessary for survival, neither wheat nor rice is" (Sen, 1981: 24). It is possible to translate characteristics in terms of commodities, but characteristic needs are sometimes easier to work with, especially when taking taste into account. Sen continues: "[there] is little doubt that ultimately characteristics provide the more relevant basis for specification of basic needs, but the relative inflexibility of taste factors makes the conversion of these basic needs into minimum cost diets a function not merely of prices but also of consumption habits" (Sen, 1981: 26). In certain societies a majority of the diet can come from one source, like maize which makes up about 75 percent of the Malawian diet (Menon, 2007: 1). The heavy reliance on maize may be an issue in other areas as well as maize is a popular dietary choice in much of east Africa, but this research is looking specifically at the current situation in Malawi (Heisey and Smale, 1995: 4). By having a majority of their diet come from one source, some institutions believed that during times of maize shortages Malawians were simply "inflexible in their eating habits," but in reality, during the 2002 famine, Malawians had no qualms about turning to alternative crops like cassava or pumpkin to fill the place of maize (Devereux, 2002). Tastes, especially during famines, are able to change so as to alleviate starvation.

Sen's essay ends with a discussion of the entitlement theory as it is applied to four famines in different areas – Bangladesh, the Sahel, Bengal, and Ethiopia. The Ethiopian famine is slightly different from the other three as there was a crop failure significant enough to cause a decline in the availability of food, so Sen spends time explaining that while availability is an issue in that famine, access was still a major contributing factor:

> "Since the Ethiopian famine clearly was initiated by a drought, and since drought causes crop failures (and, indeed, did so in this case), it is easy to be predisposed towards accepting an explanation of the famine in terms of food availability decline (FAD). But a drought causing an agricultural or pastoral crisis not only reduces food supply; it also cuts the earnings of the agriculturalist or the pastoralist, affecting his command over food" (Sen, 1981: 88-90).

Here Sen argues that while food availability can still contribute to famine, relying on that aspect alone does not explain other causes or contributions to famine, and offers his theory as a bridge in issues where food availability decline is still a factor. He explains this through the example of crop destruction: "it matters rather little whether the crop destroyed happens to be a food crop which is consumed directly, or a cash crop which is sold to buy food. In either case the person's entitlement to food collapses. It is this collapse that directly relates to his starvation" (Sen, 1981: 120). Sen summed up where his entitlement approach to famine fit into the situation when food availability decline was also present as follows:

> "A person's ability to avoid starvation will depend both on his ownership and on the exchange entitlement mapping that he faces. A general decline in food supply may indeed cause him to be exposed to hunger through a rise in food prices with an unfavourable impact on his exchange entitlement. Even when his starvation is *caused* by food shortage in this way, his immediate reason for starvation will be the decline in his exchange entitlement" (Sen, 1981: 4).

The entitlement approach extends the understanding of famine beyond simple food supply measures and includes other aspects of the economy in order to get a more complete understanding of the famine taking place. By using the entitlement approach when analyzing famines a more complete picture of the problem will result.

Sen's entitlement approach to famine has sparked debate in the literature, not all of which has been healthy, as Ravallion (1997) opines that "[he does] not think one could reasonably say that all of this debate has been insightful or interesting" (Ravallion, 1997: 1209; Rubin, 2009: 1). This is true in some instances, such as Elahi's (2006) article where he criticized Sen's work for several reasons, most of them cosmetic choices and examples which have little to do with content. For example, Elahi criticizes the choice of title of Sen's work as he claims "readers expect the author to explain how and why famine must be treated as social deprivation" and later says "Sen skips away from a demonstration of this idea" (Elahi, 2006: 550). While Elahi claims there is no discussion of these issues in Sen's work, he later accuses him of what Rubin calls "moral concern for the non-poor" in Sen's discussion of deprivation later in the essay, thus criticizing Sen for discussing an idea that Elahi claims he did not include in his work (Elahi, 2006; Rubin, 2009: 646).

Elahi also includes an example of a subsistence peasant called "X" who, Elahi believes, "can avoid starvation by liquidating his assets" and claims that because "[from] a public policy point of view, this would suggest that X, as a subsistence peasant, deserves no public help until he liquidates his [assets]" and blames Sen's approach to famine analysis for this view, though the view's author is clearly Elahi and not Sen (Elahi, 2006: 554). The first problem with this assertion from Elahi is that starvation cannot be alleviated for everyone by asset liquidation, as the prices of the assets would fall from an excess supply, as many people would likely be taking this approach to alleviate their starvation in a famine situation. Sen touches on this idea when discussing non-subsistence farmers and pastoralists during famines: "[The] grower of cash crops, or the pastoralist heavily dependent on selling animal products, is vulnerable both to output fluctuations and to shifts in marketability of commodities and in exchange rates" (Sen, 1981: 126). Sen here explains that food security through commodity exchange is only possible when the markets are favorable for that commodity. Should the market for that commodity collapse, so too would the security for the trader. In times of famine, the general response from the people in the affected area would be to sell what they have to get food, causing the market to distort and prices to lower, thereby reducing the effectiveness of this strategy: "The decline in land and livestock prices is a common phenomenon in famine situations affecting agriculturalists, since they represent assets that the agriculturalist tries to sell to acquire food when all else fails; and the sudden increase in supply of these assets in the market cause a price decline" (Sen, 1981: 102). This phenomenon happened during the Ethiopian famine in 1972 when pastoralists sold animal products at a great loss in order to access grains, showing that the asset liquidation approach to starvation alleviation in practice fails to work (Sen, 1981).

Another problem with Elahi's claim is that he includes what he believes will be a public policy response. Rubin (2009) tackles this claim by first saying that "the entitlement approach is an approach for famine analysis (and not for poverty alleviation or public policy targeting in a broader sense)" and then admitting that "the approach has yet to fully catch on in the famine prevention policy work of donor countries, international organisations and national governments alike," so any speculation on how this approach will influence public policy is pure speculation (Rubin, 2009: 1, 8). Rubin continues further by stating that Elahi is "exaggerating the political impact of the entitlement approach" and that his response "builds on the – rather unfounded – inference that public policy based on the entitlement approach would force subsistence peasants to liquidate their assets in order for them to receive public assistance. Such [a] serious accusation must be founded on a minimum of empirical evidence" which Elahi fails to provide (Rubin, 2009: 10).

Elahi also presents an interesting critique about Sen's famine framework in that it is only useful when looking at food. Elahi begins this by claiming that since food is "differentiated from all other commodities" in Sen's analysis, perhaps "other basic necessities of life, such as healthcare, education and so on, should also get the same status" (Elahi, 2006: 556). Elahi explains that in these cases "[the] fundamental problem is that Sen's theory cannot cover those services, because the poor cannot afford them with their limited endowment" (Elahi, 2006: 556). This point of Elahi's has been criticized by Rubin (2009) as he explains "the fact that an analytical framework has been developed to analyze famine and food security issues can never logically in any way 'disqualify the poor from entitlement of many life-saving services' such as education and healthcare" (Rubin, 2009: 647). Rubin's critique of Elahi's analysis of Sen's work also points out that "Elahi does not apparently believe in contributing with suggestions as to how the research agenda should move forward" and continues by asking: "[if] Sen's entitlement approach is truly useless (or even counterproductive), what then is Elahi's recommended direction for contemporary famine analysis" (Rubin, 2009: 647)? In his article, Elahi does neglect to address avenues for future work in the field of famine analysis, or how to fix the portion of Sen's work with which he disagrees (Elahi, 2006).

Rubin does describe several areas in which Sen's entitlement approach may be improved – mostly relating to issues of politics (Rubin, 2009). Rubin's call for more conflict studies originates from the idea that "fewer contemporary famines take place outside the realm of conflict and war" and that "food access was constrained in 2001 by political or armed conflicts in more than half the countries in Sub-Saharan Africa" (Rubin, 2009: 13; Kidane, et al., 2006: 22). Rubin makes clear that his point was that "famines have become more directly linked to civil war, the absence or downright breakdown of legal structures, and political manipulation" and that while "[in] none of the empirical examples that Sen used to show the superiority of the entitlement approach […] did these three factors stand out" but Rubin is confident that "[if] Sen were to choose four famines today, the chances of him picking four famines in which these features do not dominate would be nil" (Rubin, 2009: 13-14). The lack of conflict in Sen's famine analysis was also the critique of Kula, (1987) Jenkins and Scanlan, (2001) and Nolan (1993) who went so far as to say "the areas worst affected by famine in both the 1970s and the early 1980s were those also worst affected by warfare" (Nolan, 1993; Rubin, 2009: 14; Jenkins and Scanlan, 2001; Kula, 1987; von Braun, et al., 1998; Howard-Hassmann, 2005; de Waal, 1993). Sen had responded to the issue of war in part, when he gave the example that during World War II in Britain "British life expectancy rate at birth actually rose substantially compared to other decades" implying that "[war] by itself is not a sufficient condition for famine" (Drèze and Sen, 1989: 180; Rubin, 2009: 15). This idea was continued by Jenkins and Scanlan (2001) when they claimed "military build-up and war affects the overall supply of calories but does not seem to have an impact on hunger" and point to "legal/institutional collapse together with some political interest in upholding the famine" as factors in situations of war (Rubin, 2009: 15; Jenkins and Scanlan, 2001).

There is also interest in extending understanding about how the entitlement approach operates at the political level, and many authors "point out the need to include a political perspective in the approach to famine" (Rubin, 2009: 19; De Waal, 1997; Keen, 1993; Crow, 1992). The example of Zimbabwe was given as members of the military were under orders to carry out "a policy of withholding food from local areas where the ZAPU [anti-government] movement enjoyed support" (Rubin, 2009; Alexander, 1991; De Waal, 1997). Zimbabwe again enters the literature when in 2003 "Mugabe distributed food to political supporters and withheld it from his political opponents; and he refused to permit international food agencies into the country to help the starving" (Rubin, 2009: 20; Howard-Hassmann, 2005: 502). Justification for the inclusion of the political perspective in famine analysis is given by Rubin: "[if] the entitlement failure is caused by *deliberate* political action rather than *unintended* market/government failures, the approach would have limited explanatory power if not supplemented with analysis at the political level" (Rubin, 2009: 20). While Sen's work would benefit from extensions, like those suggested above, his framework still gives great insight into famines resulting from problems other than the decline of food availability.

2.2: Vulnerability, Food Security, and Mitigation

In order to see farm planning strategies through game theory and linear programming as mitigating responses to modern famine, one must first establish that these strategies can be one of the first steps in attaining food security, informing policy, and preventing a modern famine hazard. One of the easiest ways to do this is to connect the issue of modern famine to the natural hazards literature in Geography. This connection is crucial as this type of famine is not technically a "natural" hazard, but the resulting situation caused by a modern famine could benefit from the terms and analysis most often used in the natural hazards literature. This analysis results from the scrutiny of many "geographers [who] have long been concerned with natural hazards, with early research focusing on understanding physical processes" – in this case, these would be natural famines (Montz and Tobin, 2011: 1). The literature, however, has since begun a "new era of hazards research focused specifically on solving societal problems," which allows for the inclusion of hazards caused by things other than natural events – like modern, man-made famines, such as will be examined here (Montz and Tobin, 2011: 1). Montz and Tobin regard this new direction in the literature as a "stark contrast to more popular accounts following disasters […] which were mainly descriptive rather than analytical, and placed responsibility for catastrophe firmly on nature and not human endeavors" (Montz and Tobin, 2011: 1). This proposed research into modern famines will focus more on the human side (the plan) and less on the effects of nature.

Conway describes two different types of hazards: "1. *Stresses* – gradual buildup of adverse events (e.g., increasing temperatures, rising sea levels, greater or lesser rainfall) 2. *Shocks* – usually dramatic, largely unexpected events (e.g., sudden floods, cyclones, earthquakes, tsunamis, disease outbreaks)" (Conway, 2012: 300). Famines are often caused by production shocks, such as droughts or floods, which decrease the total food supply of an area, but these are not the only causes of famine. McGregor points out in his analysis of Sen's entitlement approach to famine that "famines have occurred without a significant fall in the local supplies of food" (McGregor, 1998: 623; Sen, 1981). This claim is further backed by Reid who states that "[early] disaster researchers conceptualized a disaster as an event created by the natural environment, but contemporary disaster researchers recognize that social and human-made factors also contribute to the occurrence of a disaster" (Reid, 2013: 984). This viewpoint fits in with Sen's entitlement approach to famine that societal factors can create and worsen situations of famine. Reid further states that "at this point, scholars across disciplines agree that disasters are socially constructed – the result of historical and contemporary socioeconomic factors" (Reid, 2013: 984). Since certain famines are then shaped by events beyond those naturally occurring, a new category needed to be formed to classify these disasters. These new modern famines can be avoided entirely through the use of preventative measures – in the case of this research, the idea of food self-sufficiency for the prevention of entitlement collapse will be explored. The idea that famines are preventable is echoed by Rubin in his paper analyzing the 2002 Malawi famine: "modern famine analysis has now moved focus to failures at the political level. The reason is that contemporary famines are inherently political because they are almost always preventable" (Rubin, 2008: 47). This provides testimony that Malawi experiences modern famines and that these modern famines being experienced are preventable, and should be studied further in the interest of cessation (Rubin, 2008).

Adger also backs the claim that modern famines can be prevented through planning by declaring that "[vulnerability] to food insecurity is explained, through so-called entitlement theory, as a set of linked economic and institutional factors. […] Food insecurity is therefore a consequence of human activity, which can be prevented by modified behaviour" (Adger, 2006: 270). Adger echoes and agrees with Sen's entitlement approach by concluding that "[famines] and other crises occur when entitlements fail" (Adger, 2006: 271). Here, he also introduces the idea of vulnerability from the hazards perspective into the discussion on food security and modern famines. By identifying a certain population or area as "vulnerable" to a hazard, more attention might be given to this area in an attempt to decrease this vulnerability. The hazards perspective is useful for determining vulnerability, however one complication with using the hazards perspective as a scope for viewing modern famine is that certain terms – like vulnerability – have slightly different definitions depending on the author discussing them. For example, Adger defines vulnerability as "the result of processes in which humans actively engage and which they can almost always prevent" (Adger, 2006: 270). This definition is useful in analyzing a particular system which might have a role in either keeping people at risk for damage from a certain type of hazard or failing to adequately protect people from damage resulting from a hazard.

Other definitions get slightly more specific by speaking about the at-risk population, as Montz and Tobin do when they claim that "vulnerability [was seen] as a human induced situation resulting from the availability and distribution of resources as well as public policies that marginalized some groups" (Montz and Tobin, 2011: 2). Fothergill also cites the at-risk population in his definition, but also extends it to cover efforts of resistance to, and recovery from, a particular hazard: "[vulnerability], in the disaster context, is a person's or a group's "capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard" (Blaikie, et al., 1994: 9; Fothergill, 2004: 90). Many authors have begun discussing the genesis of the term before adding their own contribution to the definition, as Luers does in her paper. She begins by stating that "[vulnerability] has been defined as the potential for loss […] and is often understood to have two sides: an external side of shocks and perturbations to which a system is exposed; and an internal side which represents the ability or lack of ability to adequately respond to and recover from external stresses" (Luers, 2003: 256). Luers extends the scope of the at-risk population to include a larger part of the ecosystem as well as the people living or working within that particular ecosystem for her own analysis: "[vulnerability], defined here as the degree to which human and environmental systems are likely to experience harm due to a perturbation or stress" (Luers, 2003: 255). Cutter presents the idea of vulnerability as "a function of the exposure (who or what is at risk) and sensitivity of the system (the degree to which people and places can be harmed)" (Adger, 2006; Cutter, 1996; Cutter, 2008: 599). One benefit through the use of this perspective is that the terms most frequently used to discuss these hazards are vague enough to be applied to a number of situations, as there are numerous hazards discussed in the literature and any official definition that gets too specific would be too limiting for certain projects or analyses. It is this situation that allows for each author to be given the opportunity to define their terms to match their needs and to defend their new definitions through their analysis.

Vulnerability, here, will be discussed in relation to food security, as hunger and modern famines result from a lack of food security within an area. Much like vulnerability, food security – sometimes called food insecurity – has a number of definitions. Conway offers his perspective on the definition from his book tackling world food security: "[*food] security*, which implies the absence of hunger, is one of those apparently straightforward concepts that appears amenable to common-sense definition. But, somewhat surprisingly, it has been the subject of much debate" (Conway, 2012: 3; Smith, et al., 1992). The Institute of Development Studies through Sussex University "identified some two hundred different definitions" for the term "food security," so clearly there is still debate over the term (Conway, 2012: 3; Smith, et al., 1992). Conway also presents other definitions of the term from significant organizations: "the World Bank adopted the following definition of food security in 1986: "Food security is access by all people at all times to enough food for an active, healthy life" (Conway, 2012: 66; World Bank, 1986). The definition from the World Bank is more specific than Conway's definition, but both describe the same situation.

The FAO expanded on the World Bank's definition later when they adopted the idea that "[food] security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Conway, 2012: 66; FAO, 2002). This definition was the response to several issues that were raised in the food security debate, mostly over scale. Conway mentioned this in his discussion of the debate over the term: "[the] controversy over the definition arises, in part, because food security operates at many different levels and over different time scales: It can apply to the globe as a whole, to a region such as Sub-Saharan Africa, or to an individual country, community, or household. These different levels relate only very loosely to each other" (Conway, 2012: 3). He continues his explanation by giving examples as to why these points are issues for creating a permanent term definition: "[a] country can be food secure, but a household may not. Sometimes lack of sufficient food can be temporary, although devastating; at others, it is persistent and seemingly intractable" (Conway, 2012: 3). Like vulnerability, the lack of an accepted definition of the term can be beneficial, because it gives each author the ability to adapt the term to their specific analysis, and does not exclude any projects or analysis from the field, allowing for a greater diversity of subjects dealing with food security.

Food security can result from many different factors, as Conway explains: “natural disasters are not the sole cause of food crises. Harvest failures often play a role, but equally important are warfare, piracy, speculation, and political mismanagement” (Conway, 2012: 65). Rubin (2009) also expressed this sentiment with regard to Sen’s (1981) entitlement approach to famine when he suggested avenues for further research in regards to war and political problems’ roles in famine. These suggested causes, as well as others not mentioned here, do impact food security at least partially, and it is because of the number of possible causes of food security that the term “has been subject to so much debate” (Conway, 2012: 65; Smith, et al., 1992; FAO, 2003). Those considered vulnerable in this study will be food insecure smallholder farmers in Malawi. A farmer shall be considered food insecure if they experience a deficit of any amount of food for their household.

Like vulnerability, mitigation is another term of many definitions and partial controversy. Vulnerability tends to define the at-risk entity in a disaster, and mitigation usually defines the efforts that should be taken in the future to lessen the impacts of the disaster on the vulnerable entity. In this study, suggestions for mitigation in the case of a famine disaster will come in the form of a planning strategy for those defined as vulnerable. This idea comes from Menon’s (2007) work when he stated that “social protection measures can be especially important policy instruments to mitigate vulnerability” (Menon, 2007: 8). Bogard uses a definition in the same vein as Menon’s, but differing slightly by gaining specificity: “mitigation is defined as any action – collective or individual, public or private –

taken to reduce the potential harm posed by an environmental hazard" (Bogard, 1988: 148). This definition seems to point to mitigation as a positive strategy since reduction from harm is normally the intention of many who work in the field of hazards research. Bogard extends his definition by later including the reasoning behind the idea: "the intention of mitigation is to reduce the hazard potential within someone's environment, that is, to lessen the chance for harm to persons from future environmental events" (Bogard, 1988: 158). After explaining the positive side of mitigation, Bogard then begins to outline the other side of the mitigation argument: "mitigation itself *produces* certain effects, that is, actively changes the parameters of the future environmental event with which it is concerned" (Bogard, 1988: 157). By changing the environment through some act of mitigation, Bogard then claims that "the theoretical possibility is opened for mitigation to produce just the opposite effect of what it intends. In other words, mitigation may actually increase the hazard potential within the environment due to outcomes that are unanticipated at the time choices concerning mitigation are made" (Bogard, 1988: 158-9).

While Bogard poses an interesting argument, his work is mostly theoretical, and many other geographers warn about "the realization of the mismatch between theory and reality" where sometimes scientists find that occasionally in practice their "theories and their models proved to be static" and therefore not as useful as they appear (Golledge, 2007: 244). This critique was first presented in an analysis of behavioral geography, but seems to be applicable to Bogard's discussion of the theory of mitigation efforts. This is backed up by previous work from other geographers who claim that "[it] also needs to be stressed that numerous studies are required before general conclusions can be reached" (Ilbery, 1978: 460). This is especially true in the hazards field, as mitigation efforts are worthy of pursuing in an attempt to decrease vulnerability. There is also a bit of a mitigation paradox in some cases, an idea on which Bogard expands later, specifically citing the famine hazard: "Relief supplies of food sent to regions stricken by drought are routinely seen as a necessary mitigation against famine, and they undoubtedly save many lives. But if too much aid is forthcoming […] the result may be bottlenecks in distribution, economic disruption, or long-term dependence of populations on outside help" (Bogard, 1988: 159). While this particular outcome is potentially possible, Bogard only looks at one specific type of famine mitigation, which usually comes after the disaster is in full-swing.

By using strategies for mitigation before the famine has a chance to strike, the harmful effects Bogard enumerated in his statement will never have the opportunity of becoming problems. Fothergill outlines this type of mitigation strategy further by discussing preparedness: "[preparedness] is the stage of a disaster involving all pre-event preparation activities and mitigation efforts in advance of a specific warning" (Fothergill, 1999: 158). Preparedness and pre-disaster mitigation are especially important strategies for Malawi as famines in the past could have been curbed by proactive mitigation, and mitigation strategies which rely too heavily on transportation are likely not going to be viable in Malawi, a comfort to Bogard's school of thought. Transportation in Malawi is costly, and at times unreliable (Lall, 2009; GFDRR, 2011: 11; Lele, 1990: 1211; Devereux, 2002: 75). It is generally difficult "[because] Malawi is landlocked, [and] it has high transport costs which hinder an effective, trade-oriented food security strategy," generally leaving the population to rely on their own food sources, which are also impacted by the floods (Lele, 1990: 1211). Devereux explained that "the floods that caused harvest failures [in 2001] also washed away feeder roads, bridges and railway lines, disrupting the movement of food both into and inside

Malawi," making it difficult to move people and supplies either out of danger or to where they were needed (Devereux, 2002: 75). Shocks to the road or rail network in Malawi are crippling because "roads account for more than 70% of the internal freight and over 90% of the country's international freight traffic" and "rail has historically been the main mode of international freight transport" for Malawi" (Lall, 2009: 4). Menon describes the factors contributing to the 2002 Malawian famine: "It is evident now that the confluence of two sets of factors – vulnerable livelihoods and weak institutions – resulted in turning what could have minimally been a natural hazard into a full-blown famine in 2002" (Menon, 2007: 4).

One issue with mitigation efforts in areas – especially in peripheral countries – can occasionally be the source of the capital for these strategies. Certain strategies might be easier than others to implement in specific areas based on the availability of government assistance and the affluence of the population. Morrow discusses this issue in relation to hazards in core countries, so one can imagine how much more of a problem mitigation would be in a peripheral one: "[poor] households have insufficient financial reserves for purchasing supplies in anticipation of an event or for buying services and materials in the aftermath. The impact is likely to affect them disproportionately, including higher mortality rates" (Morrow, 1999: 3). This would lead to a mitigation strategy that is more aimed at the community level or is funded by the government. It is important to get the government and other agencies involved in some mitigation efforts to stave off modern famine as "there will be many people who cannot afford to purchase sufficient calories and nutrients for a healthy life and who will require social protection programs to increase their ability to obtain food" (Godfray, 2010: 812). Paarlberg (2010) presented a concern from Robert Zoellick, then president of the World Bank, about the ability of the poor to access food or supply capital for mitigation strategies: “high food prices [are] particularly dangerous in poor countries where the purchase of food requires half to three-quarters of a person’s income. “There is no margin for survival,” [Zoellick] said” (Paarlberg, 2010: 23). If access to capital is a problem, the proposed mitigation strategies must either be relatively cheap to implement or be at least partly sponsored by the government or other organizations. Morrow echoes these conclusions by stating that “[from] a community standpoint, the poor are likely to require substantial government assistance” (Morrow, 1999: 4).

Pelling adds to Morrow’s conclusions about poorer households being less able to handle mitigation strategies by stating that “poor households are always having to make resource expenditure decisions which ‘play-off’ poverty and vulnerability, and invariably are forced to choose pathways that respond to the more immediate pressures of poverty over vulnerability” (Pelling, 1998: 472). Pelling concludes that poor households usually have more immediate needs that require their resources, so mitigation for potential future disasters often is deemed unimportant. A study about perceived flood risk in Puerto Rico shows this phenomenon in action as the researchers found that “[although] floods were a concern, the immediacy posed by everyday worries about well-being, livelihoods, and family resulted in floods being a less important and severe concern” (Lopez-Marrero, 2010: 287). This attitude, however, must be challenged and changed in order to move forward, as Morrow later concludes about mitigation that “[in] addition to reducing human suffering, the economic savings could be substantial” (Morrow, 1999: 8). Governments and other organizations might be more likely to fund mitigation strategies if they are seen as being more effective in the long run at improving the lives of their citizens in economic terms rather than by decreasing their vulnerability to a particular hazard.

Mitigation is not the panacea for all problems related to disasters, be they natural or otherwise, however, it can be helpful in lessening the extent of the damage. Rose touches on this point when he concludes that "all future disasters cannot be prevented" but "[what] is often overlooked is the fact that individuals, institutions, and communities have the ability to deflect, withstand, and rebound from serious shocks in terms of the course of their ordinary activities or through ingenuity and perseverance in the face of a crisis" (Rose, 2007: 383). Rose here explains that mitigation can happen on several levels in society, and doesn't have to be left up to any one level exclusively, but has the ability to be carried out by several of them for the betterment of the entire society. This idea is extended by Tribbia:

> "local managers and planners, public works officials, local and state elected officials, and community development specialists are at the forefront of making decisions that impact the social, political, and economic well-being of their local communities. Specific information and knowledge about the social, economic, and environmental conditions of a community are needed to make decisions that enhance the community's development and well-being while minimizing the potentially adverse social and environmental impacts" (Tribbia, 2008: 315).

The responsibility here is also extended to the scientists and researchers working in a particular area. This is occasionally an issue as sometimes scientists and government officials or policy-makers don't see eye-to-eye, however Montz and Tobin believe that part of this problem lies in a lack of communication: "some responsibility for a failure to communicate effectively also lies with hazard managers and academics" (Montz and Tobin, 2011: 3). Tribbia agrees with this and claims that "a disconnect remains at the intersection between science and decision-making, i.e., between the information and knowledge produced by scientists and the information and knowledge applied by decision makers" (Tribbia, 2008: 316). Communication between groups across all levels could stand to be improved for mitigation purposes as community leaders can inform scientists about specific issues in their areas, and “scientific information can […] inform decision-making” (Tribbia, 2008: 317). Informed decisions about hazard mitigation are crucial to planning efforts because, as Norris asserts, “[if] the underlying cause of an illness can be removed from the population, susceptibility of individuals within the population ceases to matter” (Norris, 2008: 145). If an effective plan can be implemented to prevent a modern famine, then subsequent problems like malnourishment and food insecurity will decrease in severity.

2.3: Content Analysis Papers

To answer the first research question, a content analysis was preformed of the literature relating to famine mitigation from two databases, the Web of Science and EBSCOHost’s Academic Search Premier. The following are a presentation of how the concepts of famine and mitigation were used in this collection of literature. The rest of the content analysis will be discussed in the results and discussion section of this document.

Unfortunately, two of the returned search results from the Web of Science database, Davies’ “Public Institutions, People, and Famine Mitigation” which appeared in the 1994 Institute of Development Studies Bulletin and Davies’ “Are Coping Strategies a Cop-Out” which appeared in the 1993 Institute of Development Studies Bulletin, were unable to be accessed and are therefore not included in this research. In addition the article “Repeated food and nutritional crises in Niger: The emergency for a renewal in food security policies” by Michiels, Egg, and Blein appearing in Cahiers Agricultures was excluded for linguistic reasons as it appeared in French. The abstract did seem to point to a modern famine approach to their research as it claimed that the “origin of the crisis had no direct link with any shock, but rather with the impoverishment process bearing upon rural households which led to a crisis impeding accessibility of foodstuffs" (Michiels, et al., 2012). It was unclear if mitigation strategies were discussed in the bulk of the article.

Of the remaining articles, some were returned for nominal use of the terms "famine" and "mitigation." Kjellstrom and McMichael's paper "Climate change threats to population health and well-being: the imperative of protective solutions that will last" appeared in Global Health Beyond in 2013 falls under this category. It is not useful to the type of research presented here as it nominally food crises as a result of climate change or environmental shocks, and the only mitigation strategies offered are those aimed at mitigating climate change, not famine (Kjellstrom and McMichael, 2013). The article "Sheep Husbandry Under Changing Climate Scenario in India: An Overview" was published in the journal Field Crops Research in 2015 and was not useful to this research as it spoke of a traditional famine brought on by drought and its effects specifically on livestock grazing (Shinde and Sejian, 2013). Mitigation was mentioned, however it was in regards to changing strategies for herding in an attempt to protect the sheep industry, and not a strategy for mitigating the famine itself (Shinde and Sejian, 2013).

Another article, which was determined as not useful for this research, was "Unifying Themes in Microbial Associations with Animal and Plant Hosts Described Using the Gene Ontology" by Torto-Alalibo, et al. and was published in Microbiology and Molecular Biology Reviews in 2010. This result was returned because the Irish potato famine pathogen was being studied (Torto-Alalibo, et al., 2010). Roy's article "State, Society and Market in the Aftermath of Natural Disasters in Colonial India: A Preliminary Exploration" published in 2008 in the Indian Economic and Social History Review was also stricken from the pool of useful results as did not discuss famine except to remove it from the scope of the research being done in the article (Roy, 2008). Tanguy, et al. produced a paper in the Bulletin of Volcanology discussing causes of eruption related deaths called "Victims from volcanic eruptions: a revised database" which was not useful here as the mitigation discussed was in relation to the eruption of the volcano, and not famine, and famine was only mentioned as a cause of death after an eruption (Tanguy, et al., 1998).

The paper "Regional drought monitoring centers – The case of eastern and southern Africa" was also unhelpful as is solely discussed traditional famines resulting from droughts, and discussed mitigation as having centers for advanced warning in the case of "extreme weather events" (Ambenje, 2000). Neumayer and Plumper's paper "The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life expectancy, 1981-2002" was also not going to be useful in this research as it looks at the outcomes of traditional famine, as well as other natural disasters, on the population, and does not mention any suggestions for mitigation for any disaster (Neumayer and Plumper, 2007). Paeth and Otto's article "The population's view on climate change and mitigation-inferences for media and policy" was equally unhelpful as it discussed the perception of climate change mitigation in the media in relation to other factors, one of which was a nominal mention of famine (Paeth and Otto, 2009). "Intra-seasonal NDVI change projections in semi-arid Africa" by Funk and Brown was also not included as it discussed traditional famines brought on by environmental shocks or conditions, and mentioned no specific mitigation strategies, only that they could be more accurately guided through the use of early warning systems (Funk and Brown, 2006). Shukla, et al. produced the paper "A seasonal agricultural drought forecast system for food-insecure regions of East Africa" in which they discuss drought related famine in East Africa (Shukla, et al., 2014). The discussion of mitigation was minimal, and mostly served to explain that "early warnings of droughts are crucial" when trying to "mitigate socioeconomic losses" (Shukla, et al., 2014).

Khalil, et al. also produced a paper that will not be useful here, entitled "Dependable wireless sensor networks for reliable and secure humanitarian relief applications" published in 2014. This article was thrown out as it discusses mitigation strategies relating to data storage and technology, and only nominally mentions famine once, declaring it a disaster that "might occur any time anywhere without prior warnings" which is largely untrue as famines are fairly easy to predict in advance (Khalil, et al., 2014). The Web of Science search also yielded a book review which appeared in Disasters, about the book *Famine and Drought Mitigation in Ethiopia in the 1990s*. Both the review and the book would not be useful in this situation, however, as the book describes traditional famines and how to mitigate those with respect to drought strategies. Boos' article "Can large-scale environmental migrations be predicted?" in Global Environmental Change in 1997 also briefly discussed famine, but attributed the causes to something other than environmental factors, citing specifically "poverty, insufficient distribution system and international trade factors" though the examples given are mostly from famines due to environmental shocks, and the discussion of mitigation is centered around mitigating population migrations (Boos, 1997).

The following papers were useful to varying degrees. Burg's article "Measuring populations' vulnerabilities for famine and food security interventions: the case of Ethiopia's Chronic Vulnerability Index" appeared in Disasters in 2008 and discussed the connection between vulnerability and food security. Burg begins by discussing vulnerability analysis as it is connected to food because it was "developed as a means of identifying who is unable to obtain food and the factors that restrict their access" (Burg, 2008). He then presents Sen's entitlement theory approach to famine, indicating that the analysis presented includes both traditional famines as well as modern famines (Burg, 2008). The bulk of the paper discussed Ethiopia's Chronic Vulnerability Index (CVI), an index which takes data about various indicators and creates a map showing "the presence of particular risk factors and coping factors" which may help show the areas in Ethiopia most in need of mitigation strategies (Burg, 2008). The indicators for the index range from access to water to malaria risk and staple crop production, and more are added as the index is updated, and while this doesn't discuss specific mitigation strategies, it can be used as a tool to help identify areas in need of famine mitigation strategies (Burg, 2008).

Elagib's paper for Ecological Indicators in 2014 – "Development and application of a drought risk index for food crop yield in Eastern Sahel" – was similar to Burg's (2008) paper, but will be less useful for this research. Whereas Burg looked at both traditional and modern famine when creating the CVI, Elagib looked solely at traditional famines brought on by droughts, and only included climate and yield data in his index, while the CVI includes a plethora of indicators of various types (Elagib, 2014; Burg, 2008). Mitigation is present in his analysis through his discussion of irrigation as a form of mitigating drought, as well as the index showing areas where irrigation could be beneficial in mitigating drought, but Elagib does not discuss plans for mitigating famine (Elagib, 2014).

Teklu's paper "The Prevention and Mitigation of Famine: Policy Lessons from Botswana and Sudan" examines drought related famines in two different areas of Africa and their efforts to mitigate famine (Teklu, 1994). The famines discussed occurred in the 1980s and were connected to droughts in the areas causing both "crop failures and erosion of the livestock base" (Teklu, 1994: 37). It did discuss the differences in mitigation efforts between the two countries, which managed to prevent famine in Botswana but not in Sudan who relied largely on international support to mitigate the effects of the famine (Teklu, 1994). A lack of institutional support exacerbated the famine in Sudan, but in Botswana a number of mitigation strategies were implemented by the government that were successful enough to prevent a famine that followed a severe drought in 1984 (Teklu, 1994). Many of the strategies that worked followed poverty reduction strategies, like offering more employment opportunities to compensate for a loss of agricultural income or subsidizing agricultural inputs and livestock feed (Teklu, 1994). One of the strategies that was successful in Botswana was the crop production intervention which encouraged small farming households to become food self-sufficient, which is the goal of the strategies presented in this research (Teklu, 1994). Since these strategies were successful in preventing famine following drought conditions, they may equally be helpful in preventing other types of famine in the same area.

Grolle's paper "High-resolution mapping of rural poverty and famine vulnerability in the Sahel: a possible approach for the Republic of Niger" appeared in Population and Environment in 2013, and discussed a possible relationship between poverty and land cover by comparing interview, survey, and land cover data (Grolle, 2013). Grolle did discuss Sen's entitlement approach to famine, but the famines he discussed in the body of the paper were related to droughts. Mitigation in relation to famine in this paper mostly came in the form of the proposed mapping techniques helping the Famine Early Warning System get outside resources into the area. To be more helpful for this research mitigation efforts to help prevent the famine from occurring would have been preferred, or the proposal of any specific mitigation activities for the area aside from relying on international aid.

Engvild's paper "A review of the risks of sudden global cooling and its effects on agriculture" was interesting in that it examined famines which occur after cooling events like volcanic eruptions and extrapolates this into what may happen in a nuclear winter scenario, but only discusses famine as a consequence of environmental factors (Engvild, 2003). Engvild does discuss mitigation strategies related to crop planning strategies, like keeping cold-resistant seeds on hand, or changing to "hardy" versions of root crops to mitigate the subsequent famine brought about by a cooling event (Engvild, 2003). Coovadia and Hadingham's article in Globalization and Health in 2005 – "HIV/AIDS: Global Trends, Global Funds and Delivery Bottlenecks" – was mildly helpful with this research as it only discussed mitigation efforts in the health sector, but did focus on a non-traditional aspect of famine (Coovadia and Hadingham, 2005). It mentioned that "famines do not simply occur – they are organized by the grain trade" which points to a cause aside from environmental conditions, which would be a modern famine (Coovadia and Hadingham, 2005). They went on to further explain that their research uncovered a "new-variant famine" in many parts of the world affected by HIV/AIDS because "agricultural output, the cornerstone of production in agrarian economies, is decreasing as a result of increased mortality in the workforce" but did not suggest any avenues for mitigation of this new famine (Coovadia and Hadingham, 2005; De Waal and Whiteside, 2004).

Godber and Wall's paper "Livestock and food security: vulnerability to population growth and climate change" offered an interesting interpretation of a crop planning strategy, as they considered the keeping of livestock to be "a crucial food resource in the case of crop failures" and could use it to mitigate loss of food, especially since livestock can thrive on land "unsuitable for crop production" (Godber and Wall, 2014; IFAD, 2007; Janzen, 2011).

A majority of the paper was spent discussing a vulnerability model which could help identify countries which would benefit from investment in this livestock strategy for increased food security, and then mitigation strategies for herding livestock under scenarios of climate change were mentioned (Godber and Wall, 2014). Famine was not discussed outside of pairing the term with food security in this paper (Godber and Wall, 2014).

Bielders and Gerard's paper in Field Crops Research entitled "Millet response to microdose fertilization in south-western Niger: Effect of antecedent fertility management and environmental factors" was useful to this research. They first concluded that microdose fertilizers would be useful for all fields in their study area to combat low yields as they "result not only from low soil fertility, but also from the use of inadequate quantities or poor quality manure, from low planting densities, or from late sowing" (Bielders and Gerard, 2015). By including both environmental factors like soil fertility and planning factors like planting times and densities, the authors are able to produce a mitigation strategy which is effective in both traditional and modern famine events. They did admit later in their research that in spite of the positive results attained by the study, the "fertilization strategy still bears a high risk for farmers" relating mostly to added input costs associated with the treatment (Bielders and Gerard, 2015). While they did have some reservations about the economic risk associated with this mitigation strategy in Niger, the authors pointed out that in other areas of the Sahel – Mali and Sudan – similar fertilizer strategies were used to increase the yields with fewer economic risks (Bielders and Gerard, 2015; Aune, et al., 2007; Aune and Ousman, 2011).

Scientific Research and Essay ran an article from Nyeko in 2009 called "Environmental mitigation and regeneration through sustainable farming and food security" which discussed how food security in Ugandan communities is largely dependent on having a stable climate (Nyeko, 2009). The goal of Nyeko's research was to "introduce [a] sustainable farming system that ensures [both] high income and food production for the local community" as the current system relied "solely on annual food and low value cash crops" (Nyeko, 2009). The plan presented by Nyeko included planting perennial trees and using other types of livestock like goats to help reduce the effects of deforestation, but noted that many of the proposed efforts didn't work as people couldn't take care of the trees, were renters who lacked interest in long-term development, or had the goats from this program destroy the seedlings from this program (Nyeko, 2009). While some aspects of the project didn't turn out well, others were adopted by the National Forestry Authority because they worked so well in the study area (Nyeko, 2009). One thing that this paper includes that is lacking in other papers about the subject is a short discussion of why a change must take place. Nyeko explains that "Right from the Colonial period to date, there is no proper cash crop of significant value that has been introduced in the region. People have continued growing cotton, tobacco and food crops that have very low market value" (Nyeko, 2009: 779). Many rural areas in post-colonial Africa can claim similar circumstances, and while not all of Nyeko's recommendations were successful, many were. The research presented here does focus on annual crops, partly because they are already being grown in the study area so there won't be any educational barriers to adoption, and people who are renting land won't have any objections regarding future development that they might not get to benefit from, as they did for parts of Nyeko's plan. Nyeko's plan also focused in part on bringing goods to market for trading purposes, whereas the plan presented here focuses on food self-sufficiency to protect against low market prices.

Jennings' article from Global Policy in 2013 titled "Climate Disruption: Are We Beyond the Worst Case Scenario?" made a brief mention of reducing famine risk in the policy implications section (Jennings, 2013: 1). Jennings discusses a possible mitigation strategy for both modern and traditional famine here: "Multilateral policies for an international crop seed cooperative could significantly lessen the impacts of crop failures and low yields, reducing the risk of famine and economic effects of unstable food prices" (Jennings, 2013: 1). He goes on to explain how his strategy of a storage for different seeds would "allow for interannual switching of crop varieties based on improved seasonal climate forecasts" and "would also provide a backup for regionally adapted crop varieties in the event of disasters" (Jennings, 2013: 7). This is a type of crop planning strategy that is suggested to work for increasing the food security of a region, though there is no specific area being discussed as a candidate in this article specifically. By discussing this point in the policy implications section of his paper, however, Jennings is laying the groundwork for future research in this field.

Of the remaining articles returned only four were able to be discussed here. Unfortunately the Tidaro, et al. paper "Climate Change and Nutrition in Africa" from Journal of Hunger and Environmental Nutrition in 2015 was unavailable for use and will not be included. The paper presented by Sparks, et al. in Climate Change Biology in 2014 was returned from the search entitled "Climate change may have limited effect on global risk of potato late blight" was not useful for this particular research. It was returned likely because it mentioned the blight largely responsible for the Irish potato famine and mitigation was mentioned in connection to climate change and not to famine (Sparks, et al., 2014).

The other papers were somewhat helpful, but the results returned from Web of Science were more related to the initial inquiry. "Contemporary issues in humanitarianism: selected resources" by Eade appeared in Development in Practice in 2006 and will not be useful in this research as she states in the introduction that "for reasons of space, we have not sought to cover the areas of early warning, prevention, and mitigation associated with 'natural' disasters," although she does discuss Sen's entitlement theory in the same paragraph (Eade, 2006). The inclusion of Sen's theory does imply that if there were to be a discussion of famine from Eade it would include modern famine, but again, no such discussion took place.

Tadesse, et al. produced a paper for Natural Resources Forum in 2008 called "The need for integration of drought monitoring tools for proactive food security management in sub-Saharan Africa" which discusses reducing drought related famine through the use of drought monitoring tools and wasn't useful for this research (Tadesse, et al., 2008). The type of famine discussed here was traditional and connected strictly to drought, which makes sense as drought monitoring is upheld as a means to decreasing future famine risk in this paper (Tadesse, et al., 2008). Aside from implementing further drought monitoring centers specific mitigation strategies were not discussed (Tadesse, et al., 2008).

Stigter and Ofori's 2014 paper in the African Journal of Food, Agriculture, Nutrition and Development entitled "What climate change means for farmers in Africa: a triptych review right panel: Climate extremes and society's responses, including mitigation attempts as part of preparedness of African farmers" is one of three papers the duo has written on the subject, but is the only one returned through the search as it is the paper which discusses mitigation. Stigter and Ofori's discussion of famine is tied directly to drought events in East

Africa and the Sahel, so no discussion of modern famine is included (Stigter and Ofori, 2014). Several mitigation strategies were presented, such as “improved feed quality, improved manure management, improved fertilizer use and greater applied nitrogen efficiency” but the first priority of the strategies were to “minimize the impact of agriculture on the climate” and not maximize the potential for farmers to attain food security (Stigter and Ofori, 2014).

2.4: Game Theory and Linear Programming

Game theory, also called the theory of games, has been widely used for a variety of problems, and has been used in the past to help solve “a wide range of decision problems for farmers,” especially when considering crop planning strategies (Agrawal and Heady, 1968: 207). To begin, a game must be described. Game theory is described as “the formal study of decision-making where several players must make choices that potentially affect the interests of the other players” (Turocy and Stengel, 2001; Adeoye, et al., 2012: 372). Reneke (2009) outlined the idea of the decision in this theory as “the decision maker’s personal balance of expected payoff and risk” (Reneke, 2009: e1239). It is seen as “a useful tool used in planning under uncertainties,” and is often used in agricultural applications as farmers “must balance the risks of loss against the potential for profit among alternative management strategies” while not being able to know some of the information necessary to create an effective plan for the current year (Rasmusen, 2006; Özkan and Akçaöz, 2002; Adeoye, et al., 2012: 372). Uncertainty is described by Reneke in relation to the decision maker: “At the time the decision maker moves, NATURE’s time dependent strategy is hidden forcing the decision maker to consider NATURE’s strategy as uncertain” (Reneke, 2009: e1239). Reneke further explains that in game theory, “the decision maker will have to start with a set of assumptions because the future is unknowable," and that these assumptions are helpful in creating and simplifying a model, as it is helpful to consider "a larger problem as a collection of smaller problems" and because "no model can capture reality," so assumptions must be made (Reneke, 2009: e1240-6). Though assumptions have to be made in a model, they must be fairly realistic otherwise the results from the model will be useless in relating back to the original problem.

There are different types of game models that can be created, but this research will focus on two-person zero-sum game models. The term "person" in this instance describes the decision maker, actor, or entity involved in the game, and does not necessarily have to be a human. More often than not "[agricultural] applications of game theory to decision-making under uncertainty have most commonly revolved around the "game against Nature"" (McInerney, 1969: 269; Agrawal and Heady, 1968; Chacko, 1956; Dillon, 1958; McInerney, 1964; Moglewer, 1962). While "Nature" is the most common alternate player in an agricultural game model, it is not the only option available to game theorists analyzing agriculture as "other players are represented by outcomes in weather conditions, insect pests, crop and livestock diseases, social and political situations, and market conditions" (Agrawal and Heady, 1968: 208).

A strategy in a game model is the "complete plan of actions to be taken when the game is actually played" (Ghorbani, 2008: 597). In an agricultural game, the players' strategies may take the form of types of crops to be planted, amount of fertilizer used, or climatic state. Gould (1963) gives the example of a game model in Ghana's Barren Middle Zone, and explains that farmers "may use the land to grow the following crops, each with different degrees of resistance to dry conditions, as their main staple food: yams, cassava, maize, millet, and hill rice. In Game Theory terms the cultivation of these crops represents five strategies" (Manshard, 1961; Poleman, 1961; Gould, 1968: 291). Nature, the other player in Gould's game model, also has strategies, but Gould admits that he makes a "somewhat unrealistic assumption that the environment has only two strategies; dry years and wet years" (Gould, 1968: 291). This game would be considered a two-person five-strategy zero-sum game. While Gould admits that dividing nature's strategies as he did for the game model was unrealistic, issues of climate or climate change have not been addressed very well in the literature as of yet. Many authors gloss over climate and climate change by claiming that: "It was assumed that the effects of climate, price and other factors belonging to the past few years will be valid for the next years in the model" (Özkan and Akçaöz, 2002: 304; McInerney, 1967; Agrawal and Heady, 1968; Hazell, 1970; Miran and Dizdaroglu, 1996; Akcaoz, 2001). This assumption is also slightly unrealistic as the economy and the environment are prone to change, but is also difficult to easily account for in a game model.

Gould's game highlighted an excellent framework for setting up an agricultural decision problem using game theory, but Gould was unable to test this framework using accurate data as yield data for his study area was unavailable. Gould's study area was located in the Barren Middle Zone of Ghana, and was chosen to illustrate how game theory could be useful in areas with a "high degree of variability of […] precipitation [that] makes it difficult for the farmers to plan effectively" (Gould; 1963; 291). It is noted in his study that the data used was "chosen simply to provide an example of Game Theory" because he was unable to "obtain these critical subcensus data" needed for this type of analysis and that these "tools are outrunning our efforts to gather the necessary materials" (Gould; 1963; 292). After noting this characteristic about his data, Gould continues to explain that "extreme accuracy of data, while always desirable, is not essential in order to use Game Theory as a tool," which allows for analyses to be done in areas with incomplete or approximate data sets, which are characteristic of many areas that would benefit from this type of analysis (Gould; 1963; 292). The main goal of Gould's study of the Barren Middle Zone in Ghana was "to point out the possible utility of the Theory of Games as a tool of research and as a conceptual framework in human and economic geography" (Gould; 1963; 290). This aim was well accomplished as many agricultural studies using game theory have been published, and many authors extol the virtues of game theory analysis, like Hazell (1970) when they claimed: "In the search for useful and practical farm planning tools for situations of uncertainty, game theory survives as a candidate for consideration" (Hazell; 1970; 239).

There are several "criteria of choice" which can be used to solve a game model, such as "Wald's maximin criterion, Laplace's principle of insufficient reason, Hurwicz's optimism-pessimism criterion, and Savage's regret criterion" (Agrawal and Heady, 1968: 208; Hurwicz, 1951; Luce and Raiffa, 1957; Savage, 1951; Wald, 1950). This study will examine a game model under Wald's criterion (also called the maximin or minimax criterion). The minimax criterion came about from von Neumann's minimax theorem work where he explains that "if mixed as well as pure strategies are considered, than every matrix game has a saddlepoint and hence a saddlepoint value" (Morgenstern and von Neumann, 1944; Shubik, 1982: 222). The saddlepoint value is the point at which one player is able to maximize their minimum score and the other player is able to minimize player one's maximum score (Shubik, 1982). Decision criteria in game theory, like those listed above, are all either based on, or are variants of, the minimax criterion (Shubik, 1987).

The Wald criterion is useful in problems of food security as "Wald's model assumes total pessimism on the part of the farmer and specifies a strategy affording the maximum security level" (Agrawal and Heady, 1968: 214). This criterion was used in Ghorbani's (2008) study of contract strategies' effects on tomato yields in Iran using game theory, where he explained that Wald's criterion was useful as the "farmer takes the minimum in each row (i.e. worst outcome for […] each strategy) and then chooses the strategy which provides him the maximum payoffs of these row minimums. […] Playing in this manner, the farmer assures himself of a certain minimum under the worst circumstances" (Ghorbani, 2008: 598). Wald's criterion was also helpful in the Adeoye, et al. (2012) study of horticultural crops in Southwest Nigeria where farmers had several crop strategies against either good or bad conditions for those crops (Adeoye, et al., 2012: 373). Adeoye explained that this "pessimistic approach implies that the decision-maker should expect the worst to happen" so that the resulting plan can offer the most secure plan in terms of output (Adeoye, et al., 2012: 373). An additional study using Wald's criterion in agricultural planning came from Özkan and Akçaöz (2002) which applied game theory to crops in Turkey. The authors' choice of decision criteria was well explained: "According to the miximin criterion the farmer tries to choose "the best of the worst". This means that the farmer selects the combination of activities which will maximize his minimum income. This strategy gives the farmer maximum security" (Özkan and Akçaöz, 2002: 307). Wald's criterion has a significant base in the literature describing it as useful in certain situations for game theory.

The type of decision maker can also be described based on the decision criteria selected for analysis under game theory. Agrawal and Heady (1968) discuss the Wald criterion as useful to a specific set of farmers: "The approach is suitable for a novice, subsistence or risk-averting farmer. It might conform to the needs of a conservative farmer who has a large family, has little equity or has been constantly undergoing loss for the last few years" (Agrawal and Heady, 1968: 215). This describes, and would be therefore useful to, a subsistence farmer struggling with food security for himself and his household, and would therefore work much better than other decision criteria which describe farmers who are not averse to taking risks in the hopes of a big payoff. Agrawal continues by describing the farmer for which Wald's criterion would be useful: "If the farmer is at a subsistence living level, the common case in many developing nations, and though he would welcome yields affording a higher standard of life, he cannot take chances so that yields or income violate the subsistence bound" (Agrawal and Heady, 1968: 214). Since the farmers in this study are subsistence farmers who have experienced loss and need to attain food self-sufficiency, the Wald criterion is the appropriate choice.

Gould's study from the Barren Middle Zone in Ghana began with a two-person five-strategy zero-sum game, but Gould explains that "a payoff matrix in which one opponent has only two strategies can always be reduced to a two-by-two game which is the solution for the complete game, in this case a five-by-two" (Gould, 1963: 292). The graphical solution to Gould's game determined that hill rice and maize would be the most likely to survive and thrive under either dry or wet conditions (Gould, 1963: 292). These strategies were then put into a "two-by-two payoff matrix" and solved in order to figure out the ideal percentage of these crops which would guarantee the best crop regardless of the amount of rainfall during that year (Gould, 1963: 292). Gould finds this "critical pair" of strategies using a graphical solution, but the optimal solution to problems like this can also be found using a linear program (Gould, 1963: 292; Özkan and Akçaöz, 2002: 304).

Linear programming has been used to help solve game theory problems largely because the linear program is the dual of the game problem. While Gould used a graphical solution to determine his critical pair, the optimal solution to a game theory problem can also be attained through the use of a linear program because "much of the mathematics used in Game Theory is the same as that used in linear programming" (Gould, 1963: 290). In the study of Turkey's crops, Özkan and Akçaöz use linear programming to determine an optimal solution to their game theory problem, and explained that "[the] optimal solution to a game problem may be stated by formulating it as a linear programming problem" (Özkan and Akçaöz, 2002: 306; Gordon and Ressman, 1978). They later explain that linear programming taken alone does not account for certain factors, but can be useful in determining optimal solutions for game theory problems: "linear programming determines the maximum profit according to given data, but risk and uncertainty are not taken into consideration," which is why they are often used with game theory problems (Özkan and Akçaöz, 2002: 303).

Linear programming and game theory are also useful together as they contain similar characteristics. For example, "Linear programming problems must have three elements: objective function, constraints and non-negativity conditions. These three elements also exist in a two-person zero-sum game" (Özkan and Akçaöz, 2002: 304). Two-person games, however, are sometimes limited, and can use linear programming to create a better model of the problem:

> "Until recently the problem so defined could not be readily solved when farm constraints were incorporated. In consequence, most game planning studies reported in the literature considered such unconstrained problems as the selection of a particular crop variety or fertilizer treatment. […]

> These problems are readily solved for mixed strategy solutions for the maximin and regret criteria through linear programming" (Hazell, 1970: 240; Heady and Chandler, 1958; Luce and Raiffa, 1957).

With the inclusion of a linear program to a game model, the model can be more informative as constraints can be added, where before they were difficult to include. Hazell also explains that the inclusion of constraints on the problem works well with the maximin – also called Wald – criterion, which was found to be a successful game criterion when examining games related to subsistence farming. Not much analysis has been performed using linear programming and game theory when relating to crop planning strategies, and very little, if any at all, has been done in Malawi. This analysis will be new to the area and very useful in attempting to achieve food self-sufficiency for smallholder farmers in the area.

2.5: Malawian Climate

A presentation of the climate of Malawi is made here as there are certain regional climatic issues that will be used to modify the national crop planning strategy to be more applicable to a particular region. The climatic issues that will be used in the regional linear programs are the average annual losses from droughts and floods in a specific area. The average annual loss figures will be used as this study focuses on government assistance rather than issues of droughts or floods, but the effect of other environmental factors on yields is an area that can be expanded on in the future. There are three major administrative regions in Malawi – Northern, Central, and Southern – and each have climatic characteristics which set them slightly apart from the others. While these differences are not incredibly large, taking them into account might help create a more realistic model, and therefore better smallholder farmer productivity and a more effective planning strategy. According to Malawi

Meteorological Services (MMS), part of the Ministry of Natural Resources, Energy and Environment (MNREE) in the Department of Climate Change and Meteorological Services (DCCMS) for the Government of Malawi (GOM), "Malawi has a sub-tropical climate, which is relatively dry and strongly seasonal" (MMS, 2006). A majority of the precipitation occurs during the wet season "from November to April" and "[annual] average rainfall varies from 725mm to 2,500mm" (MMS, 2006). Following the wet season, Malawi enjoys a "cool, dry winter season" before enjoying a short two month "hot, dry season" (MMS, 2006).

Malawi runs from the latitudes 9-17°S and longitudes 32-36°E and is considered part of the Great Rift Valley in Africa (Jury and Mwafulirwa, 2002: 1290). Lake Malawi, a rift lake, makes up most of the country's eastern border, and drains via the Shire River to the larger Zambezi River to the south, a process which leaves the southern region of the country vulnerable to flooding during part of the year (Jury and Mwafulirwa, 2002: 1290-1; Pauw, et al., 2010: 5). A study of droughts determined that "[the] Southern Malawi districts of Chikwawa, Nsanje, Phalombe and Thyolo are severely drought-prone with a drought return period of one in 4 years while other districts in this region are susceptible to agricultural droughts at least one in 4 to 8 years" (Jayanthi and Husak, 2014). This same study determined the northern districts to have a drought return of "more than one in 15 years" and the central districts to be "one in 5 to 8 years" (Jayanthi and Husak, 2014). This study defined drought using the water requirement satisfaction index (WRSI) from FEWS NET, where a score of less than one indicates some sort of crop loss from lack of water (Jayanthi and Husak, 2014). The WRSI uses a combination of rainfall estimates, potential evapotransporation, soil water holding capacity, and compares them with the water needs of specific crops to determine the score of an area (Jayanthi and Husak, 2014).

The Global Facility for Disaster Reduction and Recovery has determined that "[floods] and droughts are the leading cause of chronic food security" issues, as "[floods] cause annual losses of about 12 percent of maize production in the south" and "[drought] destroys on average 4.6 percent of the maize production each year" (GFDRR, 2011: 6). These figures, however, are debated, as the Background Paper prepared for the Global Assessment Report on Disaster Risk Reduction places the average annual losses for maize production at 1.2 percent for drought, whereas the World Bank and Risk Management Solutions, Incorporated (RMSI) has estimated that this figure is between 1.1 percent and 8.6 percent, depending on the growing region and type of maize used (Jayanthi and Husak, 2014; RMSI, 2009: 66). RMSI has also estimated the loss of maize production due to flood and has generally agreed with the GFDR analysis that the average annual loss due to flooding is 12 percent of production (RMSI, 2009: 110). Part of the reason for the focus on flooding in the southern region in Malawi is that the Shire River has a tendency to flood as it drains Lake Malawi into the larger Zambezi River, and flooding generally doesn't affect other areas of the country as significantly (Ngongondo, 2011: 940-1; Jury and Gwazantini, 2002; Jury and Mwafulirwa, 2002; British Geological Survey, 2004).

Chapter 3

Data

3.1: Raw Crop Data

Crop data were collected from the CountrySTAT website. CountrySTAT is a part of the statistics division of the UNFAO focused on displaying statistics at the national level for a number of indicators. For Malawi, the information displayed on the CountrySTAT website is given by the National Statistical Office (NSO) of the Malawian government who is responsible for the “collection, analysis and dissemination of official statistics” (United Nations, 2015). To get yield information for Malawi, two sets of statistics were downloaded from the CountrySTAT website: Distribution of Area Harvested for Primary Crops (see Table A1, appendix A), and Distribution of the Production Quantity for Primary Crops (see Table A2, appendix A). Both of these sets are national level data, as sub-national data is currently unavailable. The area data was given in hectares, and the production data was given in metric tons. The production data was converted from metric tons into kilograms by multiplying each value by one thousand. The results were then divided by the area harvested for that specific crop in order to get a measure of the yield of that crop in kilograms per hectare (see Table A3, appendix A).

CountrySTAT gave data on twenty food crops for production quantity. One crop (cow pea) was excluded from this study because it did not have data on area harvested. Four crops (bambara beans, chick peas, lentils, and peas) were excluded because they had fewer than 20 years of data. Of the remaining fifteen crops, the five crops with the largest yields were selected for this study (cassava, groundnuts, maize, potato, and sweet potato). The choice to use the five largest crops was made as these crops are already widely grown, so the crops are able to survive in the climate of the study area and farmers are already familiar with how to appropriately grow these crops.

Table A3 (see appendix A) shows the yield data for every year available on the CountrySTAT website, but five years of this data were removed to be appropriate for use in the game model. The year 1983 was removed as there were no data available for either potatoes or sweet potatoes. The years 1984 through 1986 were removed as there were no data available for potatoes. The year 2002 was removed from the dataset as there is believed to be errors associated with that year. The yields for cassava in 2001 and 2003 were reported as 16,693.4 and 15,457.5, respectfully, but in 2002 the average yield was reported as 1,491,787.7 (see Table A3, appendix A). The yields for potatoes were also suspicious as in 2001 and 2003 they were reported as being 13,458.4 and 13,077.2, respectfully, but in 2002 the average yield was reported as 1,241,998.5 (see Table A3, appendix A). For these reasons, these five years were omitted from the analysis.

There are some limitations in using this dataset, aside from the reduction in years discussed above. The FAO produced a report in which they discuss the data specific to Malawi, and in it they admitted that "[issues] of data quality while being raised by various offices, were not adequately assessed as far as the magnitude of the problem is concerned" (Kambewa and Bisa Banda, 2011: 1). Some limitations arose from the inability of the author of the study to "meet […all stakeholders] at one place in order to reconcile or rationalize presentations from various offices" (Kambewa and Bisa Banda, 2011: 1). The data presented on the CountrySTAT website seems to be an amalgam of data collected by various agencies associated with the government of Malawi including: the National Statistical Office, the

Ministry of Agriculture and Food Security, the Department of Fisheries, the Department of Forestry, the Department of Climate Change and Meteorological Services, and the Ministry of Development Planning and Cooperation. Using data from multiple sources is beneficial as one can get a certain degree of confidence in a measure if several agencies report similar values, but it can also be detrimental as there may be discrepancies in the values given, and if one cannot meet with the various departments reporting the values to determine the cause of the discrepancy, the data is at risk for errors. The obvious errors seen were removed from the dataset, but the remaining data is assumed to be fairly accurate given the lack of alternatives.

For the linear program, the data was further divided into two sections – years where the government offered assistance to smallholder farmers (see Table A4, appendix A), and years where no assistance was offered or assistance was severely reduced (see Table A5, appendix A). It is assumed that the presence or absence of government assistance is the primary determinate of yields, but climate will be included as a factor in the regional linear programs. The determination between years of assistance and years of no assistance was made based on accounts from Pauw and Chibwana (Pauw and Thurlow, 2014; Chibwana, 2010). Chibwana explains that "[in] Malawi, general price subsidies coupled with subsidized credit were used in the 1970s and 80s" but that "[following] pressure from the World Bank to deregulate through a Structural Adjustment Program (SAP), the Malawi Government eliminated the use of subsidies in the early 1990s" (Chibwana, 2010: 2). The final subsidy in the early 1990s was the "Drought Recovery Inputs Project" which was last offered in 1992 (Pauw and Thurlow, 2014: 1). Since the subsidy was offered in 1992 it would affect the yield data from the following year as typical planting in Malawi occurs between November and December, and the main harvest typically occurs between April and July of the following year, so an input subsidy given during the 1992 planting would affect the 1993 harvest yields (FEWS, 2013). For this dataset, the years between 1987 and 1993 are considered years under assistance. The years of 1994 through 1998 would be considered years of no assistance, as the SAP was being carried out. Chibwana reports that "[agricultural] subsidies were reintroduced in 1998" and so would appear in the 1999 yields (Chibwana, 2010: 2). Pauw confirms this as he explains that the "Starter Pack" program was active in 1998, but was discontinued the following year (Pauw and Thurlow, 2014: 1). The Starter Pack input subsidy would then affect the yields of 1999 and 2000, so these years are considered years of assistance.

In the year 2000 a new input subsidy program was started to replace the Starter Pack scheme of the previous year, but this program – the Targeted Input Program (TIP) – was "targeted at only half of the [Starter Pack] beneficiaries" (Pauw and Thurlow, 2014: 1). There were many problems with TIP, specifically problems of consistency as the "downscaling of TIP was partly blamed for the severe food crisis of 2001/02" and so the subsidy was slightly increased the following year, but was then downscaled the year after that (Pauw and Thurlow, 2014: 1). Pauw's analysis of subsidies in Malawi shows that maize yields drastically improved after the dissolution of TIP and the implementation of the next subsidy program in 2005 (Pauw and Thurlow, 2014: 1). Since TIP reached so few farmers and was largely inconsistent in its benefits package, the years under TIP are to be considered as years under no assistance for this analysis. The TIP subsidy program was cancelled in 2005 in favor of the current subsidy program, the Farm Input Subsidy Program (FISP), which began right after the TIP program ended in 2005 and persists today (Pauw and Thurlow, 2014: 1). Thus, the years from 2006 through 2013 are considered years under assistance.

2005 is considered a year under no assistance because while the subsidies were restarted in that year, their effects would not appear until the harvest of the following year, 2006.

3.2: Plot Size Data

Farm plot size differs among regions in Malawi. By using data describing these plot size differences the crop planning strategy using national level yield data may become more regionally specific. The data used were available through the CountrySTAT website, and were uploaded by the World Food Program (WFP) through their office in Malawi. The data made available were for 12 regions in Malawi during the 2008 through 2009 planting season (see Table A8, appendix A). The twelve regions described are highlighted in Figure 3 (see appendix B). The twelve regions do not cover all of Malawi, so there are areas where no regional plan will be created, but they do include regions in the north, central, and south of the country, so each section will be represented in some way. The plot size data explained the percentage of households that farmed a plot of a certain size that year, not the total plot size available to the farmer. This means that the farmer may or may not have had a larger plot on which to plant as this measure only describes the extent to which the farmer planted in this specific year. Another limitation with this dataset is that the data comes from survey data of a small number of houses in a region, and may or may not be representative of the average in the region as a whole. This data, however, is more specific to the region being examined than the national average data.

Assuming that these measures describe the total amount of land a farmer in the selected area has available on which to plant, the data were then converted from percentages into number of households by taking the number of households interviewed and multiplying it by the percentages of households under a particular level (see Table A9, appendix A). These numbers were then rounded to the nearest whole number while not exceeding the number of households interviewed (see Table A10, appendix A). In the Lakeshore district the number of households planting fewer than 0.5 acres was 34.51, which would have been rounded up to 35, was not rounded as the resulting household number would have exceeded the number interviewed in the study. There was a similar problem in the Thyolo Mulanje Tea Estates region where the number of households cultivating 0.5 to 1 acre, 1 to 2 acres, and 4 acres or more were 135.75, 96.75, and 21.75, respectfully. All three should have been rounded up, but the resulting number of households would have exceeded those interviewed, so the number of households cultivating 4 acres or more was rounded down, while the other two were rounded up. This decision was made as this study focuses on smallholder farmers, who cultivate fewer than 5 acres, and the 4 acres or more group has the potential to be a larger farm. Another factor in the decision was that the total number of households cultivating over 4 acres was smaller than the total number of households cultivating either between 1 and 2 acres or 0.5 and 1 acre.

Weighted median measures were used to determine the average land cultivated for each region (see Table A11, appendix A). The weighted median was calculated in two steps. First, the number of households in a category was divided by the total number of households in the region, and then multiplied by the median landholding in the category. The sum of all landholding categories was then taken to produce the weighted median landholding for a region. This was given originally in acres, and then converted to hectares as the yield data is also given in hectares. The median for the category of “less than 0.5 acres” was determined to be 0.25. The median for the category of “4 acres or more” was given as 4.4712 for a number of reasons. This study examines smallholder farmers, who are determined to cultivate fewer than two hectares, or 4.9421 acres. By using 4.9421 acres as the cutoff, the resulting numbers will reflect a population of smallholder farmers, or people who have the potential to be smallholder farmers by not cultivating more than 4.9421 acres of land.

In order to determine if plot size and region are independent factors in Malawi, a Chi-Square test for independence will be performed. The plot size data is presented categorically, and by converting the percentage of households in a category to the number of households in a category, the data is in a form which makes a Chi-Square test appropriate. As mentioned before, the household data collected by the WFP was a random sample of households in an area, which is significant as a Chi-Square analysis must be performed on a random sample (Fienberg, 1985). The null hypothesis for this Chi-Square test is that the variables of plot size and region are independent. The alternative hypothesis for this Chi-Square test is that the variables are not independent. The significance level chosen for this test will be 0.01 so that if the P-value for the Chi-Square test statistic is lower the null hypothesis can be rejected. Table A12 in appendix A is the observed number of households under each category which will be used in the Chi-Square calculations. The number of households not cultivating land will not be included in the total number of households for the Chi-Square test.

The Chi-Square statistic is represented here:

$$\chi^2 = \Sigma[(O_{i,j} - E_{i,j})^2 / E_{i,j}]$$

where O is the observed data and E is the expected data for all i, j (Fienberg, 1985). Table A13 in appendix A includes the expected value frequency table, and Table A14 in appendix

A includes the Chi-Square calculation table. The value of Chi-Square for this problem is 442.8986 with 44 degrees of freedom. The degrees of freedom were calculated using this equation:

$$df = (r-1)*(c-1)$$

such that

$$i = 1, \ldots, r$$

$$j = 1, \ldots, c$$

(Fienberg, 1985: 8-12). In examining the P-values for the Chi-Square distribution table in Burt, Barber, and Rigby's *Elementary Statistics for Geographers*, the P-value of this Chi-Square test was determined to be 0.000, indicating that this result was significant and the null hypothesis can be rejected (Burt, Barber, and Rigby, 2009: 640-1). This means that region and plot size are dependent.

3.3: Production Response to Drought and Flood Data

Another way this study will attempt to regionalize the national level crop planning strategy will be to account for regional climate issues in the forms of loss of crops from droughts throughout the country, and floods in the Southern region. Two studies will be used specifically in estimating the loss of crops from droughts and floods, the RMSI 2009 report put out by the World Bank, and Pauw, Thurlow, and van Seventer's 2010 IFPRI study. These studies were chosen as they were the most recent, specific, and complete studies examining crop losses from droughts and floods in Malawi. The RMSI study examines the loss of production in three different types of maize from droughts, and estimates the loss of production of all types of maize from floods in the Southern region (RMSI, 2009). These measures are useful in tailoring a crop planning strategy to a specific place. The IFPRI study extends this research by looking at losses from other types of crops (Pauw, et al., 2010: 12-13). This study determined that for every percentage decline in the production of maize from drought, groundnuts would decrease by one-half of a percentage, and other root crops would decrease by one-quarter of a percentage, making maize the most sensitive crop to drought (Pauw, et al., 2010: 13; RMSI, 2009; MOAFS, 2007). This conversion factor will be useful in planning for average annual crop loss due to drought.

Pauw also attempted to look at losses of crops other than maize due to floods, but was only able to assume that "losses in rice and other cereals in the southern region are similar to those experienced for maize. This assumption also extends to roots, groundnuts, vegetables, and other crops. […] Although these assumptions may seem crude, a statistical analysis of correlation did not yield useful results" (Pauw, et al., 2010: 22). Pauw was unable to determine a more specific estimate as data was unavailable, but he noted that "[similar] problems were experienced by RMSI (2009)" (Pauw, et al., 2010: 22; RMSI, 2009). For this study, floods will then be seen as affecting other crops at a similar percentage of loss to maize, as was best determined by Pauw. Table 3 in Chapter 4 summarizes crop loss from both drought and flood in all regions of the country and for all types of crops.

Chapter 4

Methods

4.1: The National Linear Program

Earlier it was mentioned that some smallholder farms in the past were risking famine because they put so much of their land to work raising cash crops in the hopes that their resulting income would be large enough to purchase foodstuffs in order to sustain their household (Chibwana, 2010). If too many farmers in an area adopt this strategy and the price for their crop is too low, a modern famine may result. Since putting your faith into a high price for one particular crop might not end well, it might be worth it to invest in some form of famine mitigation strategy. To address the second research question – can a mix of different staple crops be determined using game theory and linear programming to give a somewhat diversified diet for smallholder farmers using five of the most common food crops produced in Malawi – two linear programs were created using national level data. The two linear programs created described planting recommendations for the farmer under strategies of government assistance or no assistance. In the interest of promoting a more diversified diet (and partially protecting against the failure of one crop), a planning strategy including the five most produced food crops in Malawi will be used. According to CountrySTAT – Malawi, the top five food crops account for 90 percent of the food yield, and make up 74.5 percent of the total harvest area, roughly. These crops are: cassava, groundnuts, maize, potatoes, and sweet potatoes. Since these five crops already grow abundantly in Malawi, it is safe to assume that farmers are able to both access adequate inputs for, and cultivate these crops successfully. This information has been supplied in a two-by-five payoff matrix below, just as Gould did in his study of the Barren Middle Zone of Ghana:

Table 1 – Five-by-Two Payoff Matrix

Crop	Average Yield under Years of Government Assistance (Kg/Ha)	Average Yield under Years of No Assistance (Kg/Ha)
Cassava	11349.97	10117.55
Groundnuts	698.80	622.04
Maize	1322.88	1133.64
Potato	11232.02	11981.49
Sweet Potato	10271.16	9708.74

This payoff matrix supplies the number of variables in the objective function of the linear program – one for each crop – and shows that two linear programs will be used – one for assistance and one for no assistance. By using this information in a linear program the solutions will yield the optimal crop planning strategy under both assistance situations.

Both linear programs had the same objective function, a minimization function aimed at minimizing the planting area given several constraints. A linear program is being used here because the objective function is linear, and all the constraints are linear. A minimization function is being used to minimize the area used for planting food crops so farmers can have the maximum area available to use in other ways, like planting cash crops. The objective function for the linear program was:

$$Minimize\ f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Where X_1 represents the area of cassava planted in hectares, X_2 represents the area of groundnuts planted in hectares, X_3 represents the area of maize planted in hectares, X_4 represents the area of potatoes planted in hectares, and X_5 represents the area of sweet potatoes planted in hectares. The five variables in the objective function represent the five strategies, or crops, available to the farmer to plant. The objective function will give the optimal amount of area that should be allocated to each crop for planting once it has been evaluated using a number of constraints. The constraints for this linear program are as follows:

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.88$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

The first constraint describes calories. C_1 represents the number of calories produced from planting one hectare of cassava, C_2 represents the number of calories produced from planting one hectare of groundnuts, C_3 represents the number of calories produced from planting one hectare of maize, C_4 represents the number of calories produced from planting one hectare of potatoes, and C_5 represents the number of calories produced from planting one hectare of sweet potatoes. The value of the constraint, 3835125, was created by taking the number of calories recommended for daily consumption by the WFP, 2100, multiplying it by five to represent the national average household size in Malawi, and then multiplying it by 365.25 to get the total number of calories required by the average household for one year (WFP, 2015).

The second constraint covers protein, where P_1 represents the amount of protein produced in grams per hectare of cassava planted, P_2 describes the same for groundnuts, P_3 for maize, P_4 for potatoes, and P_5 for sweet potatoes. The value of the second constraint also came from WFP, where the recommended daily value of protein for a person is 58 grams (WFP, 2015). This value was then multiplied by the average number of members in the household (5), and 365.25 to get the recommended value of protein a household would need annually, 105922.5 grams.

The third constraint describes fat, where F_1 represents the amount of fat in grams produced from planting a hectare of cassava, F_2 denotes the same for groundnuts, F_3 for maize, F_4 for potatoes, and F_5 for sweet potatoes. Again, the WFP's measure of 43 grams of fat per person per day was used, and multiplied again by the number of people in the average Malawian household and by 365.25 to yield 78528.75 grams (WFP, 2015). The next constraint, $X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.88$, defines how the resulting solution has to be less than or equal to the average landholding in Malawi. This insures that the plan will work for a majority of the people in the study area. The value of this constraint represents the national average as reported by the Third Integrated Household Survey, conducted in 2010-2011 (NSO Malawi, 2012). The final constraint is included to make sure no values are negative, as one cannot plant fewer than zero hectares of a crop.

The differences between the assistance and no assistance linear programs were in the yield variables. The values of *C*, *P*, and *F* differed depending on the yield of the crop, and the crop yields were affected based on the presence or absence of government assistance in the planting year. For the regional linear programs, these yields will be further adjusted based on the crop losses the region will experience from droughts and floods. The programs were evaluated in Microsoft Excel using the Solver tool, which uses the simplex method to solve linear programs. In his book about linear programming, Thie claims the method most used for solving optimization problems currently is the simplex method (Thie, 2008: 60).

Thie continues that "the [simplex] method can determine if a problem has, in fact, any feasible solutions and, if so, whether the objective function actually assumes a minimum value," which will be helpful to this study (Thie, 2008: 60). The simplex method is also useful here as the simplex solution is the dual solution of the minimax criterion in a two-person zero-sum game (Dorfman and Solow, 1987). Thie explains that the simplex method works by moving "from one basic feasible solution to another by replacing exactly one basic variable at each step, with the new basic feasible solution providing a reduced value of the objective function" (Thie, 2008: 76).

4.2: Regional Linear Programs

Three regional issues – average landholding, loss of crops due to drought, and loss of crops due to flood – will be applied to the national linear program in an attempt to regionalize it. Since data were available describing the landholding sizes of twelve areas, there will be twelve sets of regional linear programs both under assistance and not. The loss of crops due to flood will be applied only in the southern regions of the country, as flooding is only a significant issue in those areas. Loss of crops from drought will be applied based on the average annual losses for each region's location – northern, central, or southern. The losses will be applied to the yield data for the constraints of each region. For example, the loss of production from drought in maize in the central region is 6.8 percent, so regional yield figure will be 97.2 percent of the national yield figure due to the loss from the drought in this area. Regionally specific yield figures are unavailable at this time, so one of the assumptions of this research is that yields before the regionally specific average annual loss figures for droughts and floods are taken into account are consistent throughout the country. Pauw's study determined drought losses using the Standard Precipitation Index from McKee, Doesken, and Kleist (1993) as it was used in the RMSI paper whose research Pauw is extending with his study (Pauw, et al., 2010). This index was used in the original study to collect precipitation data from forty-five weather stations, and assumed a gamma distribution of rainfall from these stations (Pauw, et al., 2010). Pauw explains how droughts are determined using this index:

> The parameters are calibrated using maximum likelihood estimation, and the cumulative distribution function is then transformed into a standard normal variable, Z_i, with a mean of 0 and a standard deviation of 1 […] The Z-score of this distribution is the SPI. When rainfall levels drop below 1 standard deviation from the mean […] a drought event is declared (Pauw, et al., 2010: 3-4).

The impacts of drought are not binary as the loss in crop production depends on the severity of the drought, but this research is not looking at drought severity as it is focused on the effect of government aid. The SPI helps to define drought years, but the drought's effect on crops is also partly determined by when in the life cycle of a plant the water deficit occurs (Pauw, et al., 2010). Pauw claims that maize is most sensitive to drought when flowering, but at other times is able to tolerate water loss fairly well (Pauw, et al., 2010). Pauw took this issue of drought timing into account when calculating crop production losses (Pauw, et al., 2010).

The average annual loss figures from Pauw's study will be used here because this research is more focused on the difference between yields in years of government assistance or absence of assistance. The average annual loss figures from drought are used assuming the farmer has no access to irrigation technology, so these are droughts for rain-fed agriculture. The effects of abnormal climatic events on yields would need to be studied more in-depth in the regions of Malawi being examined before it is incorporated into the program, but this problem is an excellent avenue for further research. Crop losses from drought are larger during periods of severe drought, but for the purposes of the scope of this study it is assumed that each year will operate under the average climatic conditions for the examined region.

The regional linear programs follow the same form as the national plan explained above, but the variables *C, P*, and *F* were changed to reflect that area's loss of production from the environment, and the average landholding constraint was changed to reflect that area's weighted median landholding in hectares. Three examples will be shown here in detail to reflect the differences between the programs regionally. A detailed description of each linear program for all twelve regions can be found in Chapter five. First, the linear program for the years of assistance in the Kasungu Lilongwe Plain region, which is in the central region of the country, will be shown. The objective function was:

$$\text{Minimize } X_1 + X_2 + X_3 + X_4 + X_5$$

Where X_1 represents the area of cassava planted in hectares, X_2 represents the area of groundnuts planted in hectares, X_3 represents the area of maize planted in hectares, X_4 represents the area of potatoes planted in hectares, and X_5 represents the area of sweet potatoes planted in hectares. The constraints were:

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.8027$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

The constraints are set up the same as in the national plan, where C_i ,$(i=1, \ldots, 5)$ describes the number of calories per hectare of a crop, P_i $(i=1, \ldots, 5)$ represents the amount of protein in grams per hectare of a crop, and F_i $(i=1, \ldots, 5)$ reports the amount of fat in grams per hectare of crop, but the values have been changed to reflect regional crop gains and losses. For example, there was determined to be a 6.8 percent loss of crop yield in maize for any area in the central region of the country, so the national figure of 1137680 calories per hectare of maize produced was multiplied by 0.932 to represent the loss of production from being cultivated in the central region. This resulting figure was then multiplied by two, as it is possible to cultivate two maize crops in one year in this area, giving the figure of 2225225 calories per hectare of maize planted for a given year under assistance. Chapter five contains the linear programs for each region along with several tables describing the value of the variables for each linear program. The fourth constraint has also been changed to reflect regional landholdings, where landholding size was 0.88 hectares in the national plan, it is now 0.804 hectares here to represent the weighted median landholding for the Kasungu

Lilongwe Plain area. The landholding constraint is changed to be reflective of the specific area being examined, as opposed to using the national average landholding figure.

The study from IFPRI has determined that for every percentage of loss of maize yield, there is a loss of half a percentage in yield of groundnuts and a quarter of a percentage loss in root crop yields. This means that for this study, if there is a 6.8 percent loss in maize, there will be a 1.7 percent loss in root crop production and a 3.4 percent loss in groundnut production. These losses were applied to the amount of calories, fat, and protein produced per hectare of these crops. Cassava, potato, and sweet potato are all considered root crops. The last regional difference applied to this program was the doubling of potato production, as this region is able to support two potato crops per year (Nsanjama, 1984; Rhoades, et al., 2006).

The second area, Chitipa, Northern and Central Karonga, and Misuku Hills, is in the northern region of the country. The linear program follows the same form as that of the Kasungu Lilongwe Plain region, but the fourth constraint is changed to:

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6165$$

In addition, the average annual losses are changed to include a 6.7 percent loss of maize crop with two possible harvests per year, a 1.675 percent loss of root crops, and a 3.35 percent loss of groundnut production.

The Lakeshore area was a special case, in that it covered both the northern and southern region of the country. For this area the worst case scenario was used for the linear program, so that it could apply to all parts of the area. The linear program was the same, but the fourth constraint was changed to:

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5887$$

As this area is part of the southern region of Malawi, an 8.6 percent loss of maize production from drought was applied, along with a 2.15 percent loss of production of root crops from drought, and a 4.3 percent loss of production of groundnuts due to drought. A further twelve percent loss of production for all crops was then applied to simulate the average annual loss of production from flood conditions. This took yields down to 79.4 percent of the national plan for maize, 85.85 percent for root crops, and 83.7 percent for groundnuts. This region was able to benefit from growing two crops of maize and two crops of potatoes, however, so those changes were also applied to the variables. While the Lakeshore area is different in that it spans two regions, there were no differences between this area and other areas in the southern region as far as production losses were concerned. The differences among all regions mainly arose from the weighted median landholding value, drought and flood loss figures, and the number of potato harvests achieved annually. The Shire Highlands area is the only area in Malawi that is able to produce 3 potato harvests, whereas other areas in the central and southern region are able to produce only two, and with the exception of the Lakeshore area, the northern region is able to produce one potato harvest per year (Nsanjama, 1984; Rhoades, et al., 2006). The number of potato crops possible annually is enumerated in the following table:

Table 2 – Number of Potato Crops Possible by Region

Region	Position in Country	Number of Potato Crops that can be Planted Annually
Chitipa, North and Central Karonga, Misuku Hills	North	1
Kasungu Lilongwe Plain	Central	2
Lake Chirwa and Phalombe Plain	South	2
Lakeshore	North and South	2
Lower Shire	South	2
Middle Shire Valley	South	2
Nkhata Bay and South Karonga	North	1
Phirilongwe Hills	South	2
Rift Valley	Central	2
Shire Highlands	South	3
Thyolo Mulanje Tea Estates	South	2
Western Rumphi and Mzimba	North	1

This is a very significant difference and is likely to be the cause of differences in the solutions to the linear programs. This should significantly differentiate the regional linear program solutions from the national linear program solution. Another significant difference will be the regional crop production losses, summarized in the table below:

Table 3 – Regional Crop Losses

Region	Maize Drought Loss (Percentage of Total Yield)	Groundnut Drought Loss (Percentage of Total Yield)	Root Crop Drought Loss (Percentage of Total Yield)	Crop Loss from Flood (Percentage of Total Yield for All Crops)
North	6.7	3.35	1.675	0
Central	6.8	3.4	1.7	0
South	8.6	4.3	2.15	12

Both the annual potato crop information and the regional crop loss information will be applied to the yield values used in the linear programs for each region.

4.3: The Regional Two-by-Two Payoff Matrices

Once the linear programs determine the optimal solution for each situation in each area, the next step will be to create a two-by-two payoff matrix using the most volatile constraint in the linear program. This constraint will be found by assigning the plan from one government assistance strategy to the yield of the opposing strategy for the variables of calories, protein, and fat, to determine the factor with the largest difference in potential yield if a farmer plans for one strategy and the opposite ends up happening. These three constraints were chosen as a deficit of any of these factors would have a profound effect on a person's health. The constraint of available area of land was not chosen for these calculations as the primary goal of this research is to create a mitigation plan to reduce the possibility of a modern famine, with a secondary goal of allowing a smallholder farmer an area for growing cash crops for an income. As food is more important to the primary goal, and land availability relates more towards the secondary goal, only food constraints will be examined. The calculations for the determination of the volatile factor can be found in chapter five.

Once the most volatile factor is discovered, two-by-two matrices will be created for each set of plans, both nationally and regionally. The two-by-two payoff matrix will outline a two-person non-zero sum game, which can then be evaluated using game theory. The two-by-two matrix will describe the game from the perspective of the farmer and his outcome for planting either strategy under both types of assistance. The table below offers an example of this matrix for the national level plan:

Table 4 – Resulting Fat (g) per Hectare

	Government Strategy: Offer Assistance	Government Strategy: Offer No Assistance
Farmer Strategy: Plan for Assistance	78528.75	70387.24
Farmer Strategy: Plan for No Assistance	87708.6	78528.75

If the farmer plans for assistance and the government offers assistance, then they have met their annual fat needs, according to the table above. Likewise if the farmer plans for no assistance from the government, and they receive none, the farmer has met his needs. If, on the other hand, the farmer plans for no assistance, but receives some from the government, they see a surplus of roughly twelve percent in their annual fat production. Problems arise, however, when the farmer plans for assistance, but the government offers none, as they are left with a deficit of roughly ten percent of their required fat for the year.

Since the worst case scenario of losing access to roughly ten percent of the fat required in a year is possible if the wrong plan is chosen, the ideal criterion for this two-by-two game would be the minimax, or Wald's criterion. Earlier it was explained that Wald's criterion attempts to find the best of the worst outcome and then recommend that action as it maximizes a player's security. The primary goal of this research is to suggest a mitigation strategy for the prevention of a modern famine, so the maximization of security for the smallholder farmer is a good metric for evaluating if this plan accomplishes the goal.

4.4: Percentages of Total Cropland

To check Future Agricultures' and NASFAM's figure of sixty percent food crops to forty percent cash crops, the total recommended area cultivated as determined by the linear programs will be compared to the landholding of the region (Chirwa and Matita, 2012: 3). This will happen first with the plans from the solution to the national linear programs, followed by the solution to the regional linear programs. For the national linear programs, the total area cultivated will be compared against the average landholding figure of 0.88 hectares to achieve a percentage. For the regional linear programs, the total area cultivated as reported by the solution will be compared against the weighted median of the area to achieve an ideal percentage of land devoted to food crops for the purpose of famine mitigation.

Chapter 5

Results and Discussion

5.1: Current Famine Mitigation Literature

A content analysis of the current literature discussing famine mitigation was done by searching two different databases, EBSCOHost's Academic Search Premier and Web of Science. Both databases were searched using the term "Famine Mitigation" to return results relating to efforts or ideas about mitigating famine. The results from the databases were then examined to see first, how the article treated famine – either by describing a traditional famine or a modern one – and second, if there was any discussion about mitigation efforts with respect to the famine. The ideal type of material to be returned from the search would be a journal article published in a peer-reviewed academic journal. The search results from Web of Science will be discussed first.

The famine mitigation search on Web of Science yielded 26 results ranging in dates from 1993 to 2015, of which 22 were articles, two were reviews, one was a proceedings paper, and one was a book review. These results came from a multitude of categories including: planning development, environmental sciences, agronomy, public environmental occupational health, multidisciplinary sciences, meteorology atmospheric sciences, geosciences multidisciplinary, geography, environmental studies, biodiversity conservation, area studies, water resources, telecommunications, remote sensing, political science, microbiology, international relations, imaging science photographic technology, history, forestry, ecology, demography, computer science information systems, agriculture multidisciplinary, and agriculture dairy animal science. While some of these categories are interesting choices, many of the results can be discarded as having little to do with the initial inquiry.

The web of science articles yielded more results than the EBSCOHost Academic Search Premier search, which yielded seventeen results from 1997 to 2015 from various sources including thirteen academic journals, eight magazines, and two journals (several were cross listed as two kinds of sources). These results were pared down to include only scholarly peer-reviewed journals, and five results were excluded. Of the twelve remaining results, seven were found through the Web of Science database search conducted above: Burg (2008), Grolle (2013), Kjellstrom and McMichael (2013), Bielders and Gerard (2015), Engvild (2003), Funk and Brown (2006), and Coovadia and Hadingham (2005).

The results of this inquiry from both databases yielded 43 results total, seven of which were repeated results and ten of which were not related to the initial inquiry, leaving twenty-six results. Of these results, fourteen discussed traditional famine mostly relating to droughts, six discussed both traditional and modern famines, and none discussed modern famine alone. The research done here solely discusses modern famine and fills a gap in these databases. Of the articles which discuss mitigation from these databases, nine discussed mitigation in relation to climate change and not famine, and six offered mitigation strategies which did relate to famine specifically or crop planning strategies. This research adds to the collection of modern famine mitigation literature assembled by these databases which are underrepresented when compared to mitigation for environmental problems. The following table enumerates these results:

Table 5 – Content Analysis Results

Topic	Number of Results Returned	Percentage of Total Results	Percentage of Results Relating to Initial Inquiry
Resources with Nominal use of the Search Terms	10	27.77778	N/A
Famine	20	55.55556	76.92308
Traditional Famine Only	14	38.88889	53.84615
Modern Famine Only	0	0	0
Both Traditional and Modern Famine	6	16.66667	23.07692
Mitigation	15	41.66667	57.69231
Famine Mitigation	6	16.66667	23.07692
Other Types of Mitigation	9	25	34.61538
Crop Planning Strategies	6	16.66667	23.07692
Non-Specific Crop Planning Strategies	4	11.11111	15.38462
Specific Crop Planning Strategies	2	5.555556	7.692308

The table relates the topics covered in the articles returned from the search, including the number and percentages of articles returned. Thirty-six non-repeating results were returned from the search, though ten of these results nominally mentioned famine or mitigation, but did not discuss the topic. The column in the table above called "Percentage of Total Results" examines the number of articles returned from a topic compared to the original thirty-six from the inquiry. The column "Percentage of Results Relating to Initial Inquiry" removes the ten sources that nominally mention the search terms from the total number of articles, and relates the number of results for each topic to this number. For example, if the nominal sources are included, then roughly half of the papers returned mention famine, whereas if we remove these articles over three-quarters of the articles discuss famine.

There are several values to note in the table. One is that less than a quarter of the results discussed modern famines along with traditional famines, and that no papers were returned that discuss modern famine alone. In addition, less than one quarter of the articles discussed famine mitigation, which ends up being less than half of the articles which discuss mitigation. Four other articles, roughly fifteen percent of the results, discussed non-specific crop planning strategies. These strategies are considered non-specific because they do not discuss a plan for a specific area; they solely present an idea that might work in a particular area. Only two articles, less than ten percent of the total number of results relating to the inquiry, discussed specific crop planning strategies.

This research adds to these results in some of the less well represented areas. It will solely discuss modern famine, an area in this search which yielded no results. Modern famine is underrepresented when considering efforts of famine mitigation considering these results. Many of the mitigation plans from articles which discussed traditional famine related to efforts of irrigation to mitigate droughts. This research will also become one of the few to discuss modern famine mitigation, and will present specific crop planning strategies for twelve regions in Malawi, as well as a more general national plan. Of the articles from this search, only two had specific crop planning strategies, and both of those strategies were shown to work in their study areas, and both of those areas were in other countries in Sub-Saharan Africa.

5.2: National Plan Results

The two linear programs at the national level yielded solutions which met all the constraints. The following is the linear programming model for the national area under years of assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.88$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 6 – National Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	18159958.27
C_2	Caloric yield for one hectare of groundnuts	3962194.01
C_3	Caloric yield for one hectare of maize	2275359.98
C_4	Caloric yield for one hectare of potatoes	8648651.87
C_5	Caloric yield for one hectare of sweet potatoes	8833199.24

The following table offers the values of the variables *P* used in the linear program:

Table 7 – National Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	154359.65
P_2	Protein yield for one hectare of groundnuts	180290.31
P_3	Protein yield for one hectare of maize	86516.60
P_4	Protein yield for one hectare of potatoes	226886.71
P_5	Protein yield for one hectare of sweet potatoes	161257.24

The following table offers the values of the variables F used in the linear program:

Table 8 – National Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	31779.93
F_2	Fat yield for one hectare of groundnuts	343809.43
F_3	Fat yield for one hectare of maize	35717.86
F_4	Fat yield for one hectare of potatoes	10108.81
F_5	Fat yield for one hectare of sweet potatoes	5135.58

The following table offers the solution to the linear program:

Table 9 – National Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0350	0.2172	0	0.2704	0

Under assistance nationally, a smallholder farmer should plant roughly 0.0350 hectares of cassava, 0.2172 hectares of groundnuts, and 0.2704 hectares of potatoes, for a total of 0.5226 hectares of food crops cultivated. This plan works as it is offers a solution below the average plot size.

The following is the national area linear programming model under years where no government assistance was available:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.88$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 10 – National Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16188087.16
C_2	Caloric yield for one hectare of groundnuts	3526986.88
C_3	Caloric yield for one hectare of maize	1949856.50
C_4	Caloric yield for one hectare of potatoes	9225743.59
C_5	Caloric yield for one hectare of sweet potatoes	8349514.20

The following table offers the values of the variables *P* used in the linear program:

Table 11 – National Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137598.74
P_2	Protein yield for one hectare of groundnuts	160487.23
P_3	Protein yield for one hectare of maize	74139.90
P_4	Protein yield for one hectare of potatoes	242026.00
P_5	Protein yield for one hectare of sweet potatoes	152427.18

The following table offers the values of the variables *F* used in the linear program:

Table 12 – National Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28329.15
F_2	Fat yield for one hectare of groundnuts	306045.42
F_3	Fat yield for one hectare of maize	30608.22
F_4	Fat yield for one hectare of potatoes	10783.34
F_5	Fat yield for one hectare of sweet potatoes	4854.37

The following table offers the solution to the linear program:

Table 13 – National Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0393	0.2440	0	0.2535	0

Under no assistance nationally, the ideal solution is to plant roughly 0.0393 hectares of cassava, 0.2440 hectares of groundnuts, and 0.2535 hectares of potatoes, for a total of 0.5368 hectares. This plan works as it offers a solution below the average landholding of the area. The plan for no assistance requires the farmer to plant more cassava and groundnuts, but fewer potatoes than the plan for assistance. Neither plan for the national area recommended the planting of maize or sweet potatoes. This will likely be a controversial recommendation, as maize comprises a majority of the diet in Malawi, but maize could still be grown as either a cash crop or cultivated on any leftover land for consumption. It is interesting that while two maize crops are possible per year, the nutritional value of the other crops with a single harvest per year outweighs the value of maize cultivation nationally.

5.3: Regional Linear Program Results

Regional data were used in the creation of specific plans for twelve regions in Malawi: region one contains Chitipa, North and Central Karonga, and Misuku Hills, region two contains the Kasungu Lilongwe Plain, region three contains Lake Chirwa and Phalombe Plain, region four contains the Lakeshore districts, region five contains the Lower Shire district, region six contains the Middle Shire Valley, region seven is comprised of Nkhata Bay and South Karonga, region eight is the Phirilongwe Hills, region nine encompasses the Rift Valley, region ten describes the Shire Highlands, region eleven includes the Thyolo Mulanje Tea Estates, and region twelve consists of Western Rumphi and Mzimba (see Figure 3, Appendix B). The results for 23 of the 24 regional linear programs were promising; the only exception was the Lower Shire region under a no assistance strategy as the solution required more land than the weighted median amount of land for that region. While this one region under this strategy did not produce an optimal solution, the other regions did produce optimal solutions under both strategies.

The first region to be examined is the Chitipa, North and Central Karonga, and Misuku Hills area, which is in the northern part of the country. Being in the northern part of the country, the region is unable to cultivate more than one potato crop per year, but is able to cultivate two maize crops per year, and experiences losses due to drought but not flood. Drought losses for this region are 6.70 percent of the maize yield, 3.35 percent of the groundnut yield, and 1.675 percent of the yield for all root crops. These expected losses will be factored into the yield data for the plans in this area. The following is the linear programming model for the region of Chitipa, North and Central Karonga, and Misuku Hills under years of government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6165$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 14 – Chitipa, North and Central Karonga, Misuku Hills Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	18488993.68
C_2	Caloric yield for one hectare of groundnuts	3871077.36
C_3	Caloric yield for one hectare of maize	2227613.02
C_4	Caloric yield for one hectare of potatoes	8577481.09
C_5	Caloric yield for one hectare of sweet potatoes	8823625.80

The following table offers the values of the variables P used in the linear program:

Table 15 – Chitipa, North and Central Karonga, Misuku Hills Area Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	157156.45
P_2	Protein yield for one hectare of groundnuts	176144.26
P_3	Protein yield for one hectare of maize	84701.10
P_4	Protein yield for one hectare of potatoes	225019.63
P_5	Protein yield for one hectare of sweet potatoes	161082.47

The following table offers the values of the variables F used in the linear program:

Table 16 – Chitipa, North and Central Karonga, Misuku Hills Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	32355.74
F_2	Fat yield for one hectare of groundnuts	335903.01
F_3	Fat yield for one hectare of maize	34968.34
F_4	Fat yield for one hectare of potatoes	10025.63
F_5	Fat yield for one hectare of sweet potatoes	5130.01

The following table offers the solution to the linear program:

Table 17 – Chitipa, N. and C. Karonga, Misuku Hills Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0344	0.2223	0	0.2727	0

The following describes the Chitipa, North and Central Karonga, and Misuku Hills area linear programming model for years of no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6165$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 18 – Chitipa, North and South Karonga, Misuku Hills Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	14936291.39
C_2	Caloric yield for one hectare of groundnuts	3376959.63
C_3	Caloric yield for one hectare of maize	1655189.21
C_4	Caloric yield for one hectare of potatoes	8868965.07
C_5	Caloric yield for one hectare of sweet potatoes	8001112.98

The following table offers the values of the variables *P* used in the linear program:

Table 19 – Chitipa, North and Ccentral Karonga, Misuku Hills Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	126958.48
P_2	Protein yield for one hectare of groundnuts	153660.60
P_3	Protein yield for one hectare of maize	62935.68
P_4	Protein yield for one hectare of potatoes	232666.36
P_5	Protein yield for one hectare of sweet potatoes	146066.83

The following table offers the values of the variables *F* used in the linear program:

Table 20 – Chitipa, North and Central Karonga, Misuku Hills Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	26138.51
F_2	Fat yield for one hectare of groundnuts	293265.42
F_3	Fat yield for one hectare of maize	25982.62
F_4	Fat yield for one hectare of potatoes	10366.32
F_5	Fat yield for one hectare of sweet potatoes	4651.81

The following table offers the solution to the linear program:

Table 21 – Chitipa, North and Central Karonga, Misuku Hills Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0425	0.2547	0	0.2639	0

The solutions for these linear programs work as both the plan for assistance and no assistance are less than the weighted median land for this area.

The following set of plans describes the Kasungu Lilongwe Plain area. This area is located in the central region of the country, and is able to cultivate both an extra maize and potato crop per year. The central regions experience an average annual loss from drought of 6.8 percent for maize, 3.4 percent for groundnuts, and 1.7 percent for all root crops. The area does not experience any production losses from floods. The following explains the Kasungu Lilongwe Plain area linear program for assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.8027$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes

hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 22 – Kasungu Lilongwe Plain Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	18484292.69
C_2	Caloric yield for one hectare of groundnuts	3869074.73
C_3	Caloric yield for one hectare of maize	2225225.44
C_4	Caloric yield for one hectare of potatoes	17150600.38
C_5	Caloric yield for one hectare of sweet potatoes	8821382.31

The following table offers the values of the variables *P* used in the linear program:

Table 23 – Kasungu Lilongwe Plain Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	157116.49
P_2	Protein yield for one hectare of groundnuts	176053.14
P_3	Protein yield for one hectare of maize	84610.32
P_4	Protein yield for one hectare of potatoes	449924.84
P_5	Protein yield for one hectare of sweet potatoes	161041.51

The following table offers the values of the variables *F* used in the linear program:

Table 24 – Kasungu Lilongwe Plain Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	32347.51
F_2	Fat yield for one hectare of groundnuts	335729.24
F_3	Fat yield for one hectare of maize	34930.86
F_4	Fat yield for one hectare of potatoes	20046.16
F_5	Fat yield for one hectare of sweet potatoes	5128.71

The following table offers the solution to the linear program:

Table 25 – Kasungu Lilongwe Plain Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0344	0.2224	0	0.1364	0

The following presents the Kasungu Lilongwe Plain area linear program for years of no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.8027$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 26 – Kasungu Lilongwe Plain Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	14932493.70
C_2	Caloric yield for one hectare of groundnuts	3375212.63
C_3	Caloric yield for one hectare of maize	1653415.16
C_4	Caloric yield for one hectare of potatoes	17733420.12
C_5	Caloric yield for one hectare of sweet potatoes	7999078.62

The following table offers the values of the variables P used in the linear program:

Table 27 – Kasungu Lilongwe Plain Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	126926.20
P_2	Protein yield for one hectare of groundnuts	153581.10
P_3	Protein yield for one hectare of maize	62868.23
P_4	Protein yield for one hectare of potatoes	465214.40
P_5	Protein yield for one hectare of sweet potatoes	146029.69

The following table offers the values of the variables *F* used in the linear program:

Table 28 – Kasungu Lilongwe Plain Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	26131.86
F_2	Fat yield for one hectare of groundnuts	293113.70
F_3	Fat yield for one hectare of maize	25954.77
F_4	Fat yield for one hectare of potatoes	20727.37
F_5	Fat yield for one hectare of sweet potatoes	4650.63

The following table offers the solution to the linear program:

Table 29 – Kasungu Lilongwe Plain Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0425	0.2548	0	0.1320	0

Both of the plans for the Kasungu Lilongwe Plain area are successful as they present a solution that is less than the weighted median land available to smallholder farmers in the area.

The next region presented is the Lake Chirwa and Phalombe Plain area. This area is in the southern region of the country, and has the ability to cultivate both an extra maize and potato crop per year. This area unfortunately experiences production losses from both droughts and floods. The drought losses in this region of the country are the highest: 8.6 percent for maize, 4.3 percent for groundnuts, and 2.15 percent for all root crops. In addition to these losses, the average annual loss due to flooding in the southern regions is twelve percent for all crops. The yield data used in these models were adjusted for both of these losses. The model for the Lake Chirwa and Phalombe Plain area under assistance is as follows:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5135$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 30 – Lake Chirwa and Phalombe Plain Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	14978423.63
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables *P* used in the linear program:

Table 31 – Lake Chirwa and Phalombe Plain Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	392940.46
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables *F* used in the linear program:

Table 32 – Lake Chirwa and Phalombe Plain Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	17507.25
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 33 – Lake Chirwa and Phalombe Plain Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0394	0.2567	0	0.1561	0

The subsequent model represents the Lake Chirwa and Phalombe Plain area linear program for no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5135$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 34 – Lake Chirwa and Phalombe Plain Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	15487427.44
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables *P* used in the linear program:

Table 35 – Lake Chirwa and Phalombe Plain Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	406293.55
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables F used in the linear program:

Table 36 – Lake Chirwa and Phalombe Plain Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	18102.19
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 37 – Lake Chirwa and Phalombe Plain Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1511	0

Both of these models are seen as successful as they have generated results which are less than the weighted median land available in the area.

The Lakeshore area is a special case among the regions depicted here, as it includes areas both in the northern and southern region of the country (see Figure 1, Appendix B). While it has area in both regions, its proximity to Lake Malawi causes flooding to be a concern throughout the area, including the northern parts. Flooding is a concern, but with the threat of flooding also comes the ability to cultivate two potato crops per year, along with the ability to grow a second maize crop. Considering the similarities of the northern parts of the area to the southern parts of the area, the drought losses for the entire area will be assumed to be those of a normal southern region, as these drought losses are more severe and this model is designed to increase the food security of an area. The following model shows the Lakeshore area linear program for assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5887$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 38 – Lakeshore Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	14978423.63
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables P used in the linear program:

Table 39 – Lakeshore National Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	392940.46
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables F used in the linear program:

Table 40 – Lakeshore Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	17507.25
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 41 – Lakeshore Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0394	0.2567	0	0.1561	0

The next model represents the Lakeshore area linear program for years of no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5887$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 42 – Lakeshore Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	15487427.44
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables *P* used in the linear program:

Table 43 – Lakeshore Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	406293.55
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables F used in the linear program:

Table 44 – Lakeshore National Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	18102.19
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 45 – Lakeshore Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1511	0

The linear programming models for the lakeshore region are both good as they offer solutions under the area's weighted median landholdings.

The Lower Shire area is also a special case, as it contains the model which was unable to produce a solution beneath the weighted median landholding for the area. The Lower Shire is in the southern region of the country, so on top of the twelve percent average annual production loss from flooding, there is an 8.6 percent drought loss for maize, 4.6 percent drought loss for groundnuts, and a 2.15 percent drought loss for all root crops. In addition the Lower Shire has the smallest weighted median landholdings of the twelve regions for which data are available. The model below is the Lower Shire area linear program for assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.4733$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes

hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 46 – Lower Shire Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	14978423.63
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables *P* used in the linear program:

Table 47 – Lower Shire Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	392940.46
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables *F* used in the linear program:

Table 48 – Lower Shire Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	17507.25
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 49 – Lower Shire Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0394	0.2567	0	0.1561	0

The following model describes the Lower Shire area linear program for no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.4733$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 50 – Lower Shire Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	15487427.44
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables P used in the linear program:

Table 51 – Lower Shire Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	406293.55
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables *F* used in the linear program:

Table 52 – Lower Shire Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	18102.19
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 53 – Lower Shire Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1511	0

This solution was not ideal as it used more area than was available to a majority of the people in the area. There are two recommendations for the Lower Shire region that would allow for a better chance at food security. First, rather obviously, would be for the government to always offer assistance to the area so that the farmers can plan for assistance and attain food security every year. Second would be for farmers of the area to acquire more land for planting. This may not be possible for some farmers in the region, and is not often a recommended option, but the data about plot size did not specifically state that the plot sizes planted were the total available land for use by the farmer, in which case there could be some extra land available for planting. If this is the case, the farmers should plant at least the amount for the plan to insure food security. Again, it depends on the reason why the farmer chose not to plant to their full capacity. Perhaps there was a shortage of labor or a family illness that prevented part of the household from participating in farming activities, which could be isolated incidents and will be resolved by the following year. It is also possible that farmers are leaving a portion of their land fallow to help rejuvenate the soil as maize is quite taxing on the land. This could be resolved by planting legumes like groundnuts, a major element of these planning strategies. Groundnuts are nitrogen fixers and will not only thrive in poor soils, but will help to improve the nutrient availability in the soil (Department of Agriculture, Forestry and Fisheries, Republic of South Africa (DAFFRAS), 2010). Cassava, although a minor portion of the plan, also does well in poor soils (DAFFRAS, 2010). Many recommendations can be made to improve the plan, but they would benefit from further research in the Lower Shire area to address the specific problem.

The next area examined is the Middle Shire Valley. This area is located in the southern region of the country, and as such deals with floods and droughts, reducing the crop yields of maize by a total of 20.6 percent, groundnuts by 16.3 percent, and root crops by 14.15 percent, using average annual loss estimates. The Middle Shire Valley area linear program for assistance is presented here:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5993$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 54 – Middle Shire Valley Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	14978423.63
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables *P* used in the linear program:

Table 55 – Middle Shire Valley Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	392940.46
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables *F* used in the linear program:

Table 56 – Middle Shire Valley Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	17507.25
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 57 – Middle Shire Valley Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0394	0.2567	0	0.1561	0

The next section presents the Middle Shire Valley area linear program for years of no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5993$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 58 – Middle Shire Valley Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	15487427.44
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables *P* used in the linear program:

Table 59 – Middle Shire Valley Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	406293.55
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables *F* used in the linear program:

Table 60 – Middle Shire Valley Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	18102.19
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 61 – Middle Shire Valley Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1511	0

These plans have both attained the goal of offering a solution that was less than the weighted median landholding for smallholder farmers in the area.

The following pair of models has been tailored to fit the area comprising Nkhata Bay and South Karonga. This area is in the northern region of the country, and is able to produce two maize crops per year, but is only able to support one potato crop annually. As the area occupies the northern part of the country it escapes the damaging floods which occasionally strike the southern portion of Malawi, and experiences average annual losses from drought of 6.7 percent for maize, 3.35 percent for groundnuts, and 1.675 percent for root crops. First shown shall be the model describing assistance years in Nkhata Bay and South Karonga:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6414$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 62 – Nkhata Bay and South Karonga Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	18488993.68
C_2	Caloric yield for one hectare of groundnuts	3871077.36
C_3	Caloric yield for one hectare of maize	2227613.02
C_4	Caloric yield for one hectare of potatoes	8577481.09
C_5	Caloric yield for one hectare of sweet potatoes	8823625.80

The following table offers the values of the variables P used in the linear program:

Table 63 – Nkhata Bay and South Karonga Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	157156.45
P_2	Protein yield for one hectare of groundnuts	176144.26
P_3	Protein yield for one hectare of maize	84701.10
P_4	Protein yield for one hectare of potatoes	225019.63
P_5	Protein yield for one hectare of sweet potatoes	161082.47

The following table offers the values of the variables F used in the linear program:

Table 64 – Nkhata Bay and South Karonga Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	32355.74
F_2	Fat yield for one hectare of groundnuts	335903.01
F_3	Fat yield for one hectare of maize	34968.34
F_4	Fat yield for one hectare of potatoes	10025.63
F_5	Fat yield for one hectare of sweet potatoes	5130.01

The following table offers the solution to the linear program:

Table 65 – Nkhata Bay and South Karonga Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0344	0.2223	0	0.2727	0

Since the model for assistance has just been presented, the next model will display the linear program for no government assistance in the area of Nkhata Bay and South Karonga:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6414$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 66 – Nkhata Bay and South Karonga Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	14936291.39
C_2	Caloric yield for one hectare of groundnuts	3376959.63
C_3	Caloric yield for one hectare of maize	1655189.21
C_4	Caloric yield for one hectare of potatoes	8868965.07
C_5	Caloric yield for one hectare of sweet potatoes	8001112.98

The following table offers the values of the variables *P* used in the linear program:

Table 67 – Nkhata Bay and South Karonga Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	126958.48
P_2	Protein yield for one hectare of groundnuts	153660.60
P_3	Protein yield for one hectare of maize	62935.68
P_4	Protein yield for one hectare of potatoes	232666.36
P_5	Protein yield for one hectare of sweet potatoes	146066.83

The following table offers the values of the variables *F* used in the linear program:

Table 68 – Nkhata Bay and South Karonga Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	26138.51
F_2	Fat yield for one hectare of groundnuts	293265.42
F_3	Fat yield for one hectare of maize	25982.62
F_4	Fat yield for one hectare of potatoes	10366.32
F_5	Fat yield for one hectare of sweet potatoes	4651.81

The following table offers the solution to the linear program:

Table 69 – Nkhata Bay and South Karonga Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0425	0.2547	0	0.2639	0

The two solutions presented for Nkhata Bay and South Karonga were both less than the weighted median for the area.

Phirilongwe Hills is located in the southern part of the country, and is unfortunately at risk for production loss due to flooding. The total losses are 20.6 percent for maize, 16.3 percent for groundnuts, and 14.15 percent for all root crops annually. The losses are a combination of the twelve percent average annual production loss from flooding and various losses from drought which are consistent with the values for drought in the southern regions. The Phirilongwe Hills area is able to cultivate two crops of both maize and potatoes per year. The next section displays the model for the Phirilongwe Hills area linear program for assistance years:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6741$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes

hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 70 – Phirilongwe Hills Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	14978423.63
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables *P* used in the linear program:

Table 71 – Phirilongwe Hills Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	392940.46
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables *F* used in the linear program:

Table 72 – Phirilongwe Hills Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	17507.25
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 73 – Phirilongwe Hills Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2567	0	0.1561	0

As the previous section contained the model for government assistance, it follows that this section will describe the Phirilongwe Hills area linear program for no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6741$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 74 – Phirilongwe Hills Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	15487427.44
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables *P* used in the linear program:

Table 75 – Phirilongwe Hills Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	406293.55
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables *F* used in the linear program:

Table 76 – Phirilongwe Hills Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	18102.19
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 77 – Phirilongwe Hills Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1511	0

The Phirilongwe Hills solutions presented above are useful as they yielded results below the weighted median land for the area.

The Rift Valley area is located in the central region of Malawi, and avoids the flooding problems of areas in the southern region, while at the same time exploiting a second potato crop which can be cultivated annually, along with a second maize crop. The average annual drought loss figures for production in the Rift Valley are 6.8 percent for maize, 3.4 percent for groundnuts, and 1.7 percent for all root crops. The presentation of the linear programming model for assistance in the Rift Valley commences below:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5916$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 78 – Rift Valley Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	18484292.69
C_2	Caloric yield for one hectare of groundnuts	3869074.73
C_3	Caloric yield for one hectare of maize	2225225.44
C_4	Caloric yield for one hectare of potatoes	17150600.38
C_5	Caloric yield for one hectare of sweet potatoes	8821382.31

The following table offers the values of the variables *P* used in the linear program:

Table 79 – Rift Valley Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	157116.49
P_2	Protein yield for one hectare of groundnuts	176053.14
P_3	Protein yield for one hectare of maize	84610.32
P_4	Protein yield for one hectare of potatoes	449924.84
P_5	Protein yield for one hectare of sweet potatoes	161041.51

The following table offers the values of the variables *F* used in the linear program:

Table 80 – Rift Valley Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	32347.51
F_2	Fat yield for one hectare of groundnuts	335729.24
F_3	Fat yield for one hectare of maize	34930.86
F_4	Fat yield for one hectare of potatoes	20046.16
F_5	Fat yield for one hectare of sweet potatoes	5128.71

The following table offers the solution to the linear program:

Table 81 – Rift Valley Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0344	0.2224	0	0.1364	0

The next section presents the Rift Valley area linear programming model for no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5916$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 82 – Rift Valley Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	14932493.70
C_2	Caloric yield for one hectare of groundnuts	3375212.63
C_3	Caloric yield for one hectare of maize	1653415.16
C_4	Caloric yield for one hectare of potatoes	17733420.12
C_5	Caloric yield for one hectare of sweet potatoes	7999078.62

The following table offers the values of the variables *P* used in the linear program:

Table 83 – Rift Valley Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	126926.20
P_2	Protein yield for one hectare of groundnuts	153581.10
P_3	Protein yield for one hectare of maize	62868.23
P_4	Protein yield for one hectare of potatoes	465214.40
P_5	Protein yield for one hectare of sweet potatoes	146029.69

The following table offers the values of the variables F used in the linear program:

Table 84 – Rift Valley Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	26131.86
F_2	Fat yield for one hectare of groundnuts	293113.70
F_3	Fat yield for one hectare of maize	25954.78
F_4	Fat yield for one hectare of potatoes	20727.37
F_5	Fat yield for one hectare of sweet potatoes	4650.63

The following table offers the solution to the linear program:

Table 85 – Rift Valley Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0425	0.2548	0	0.1320	0

Both of the solutions for the Rift Valley have met the standard of being below the weighted median for the area.

The only area of Malawi which is able to produce a third potato crop annually is the Shire Highlands area. In addition to this third potato crop, it is able to produce a second maize crop annually. This area is located in the southern region of the country, and does have the possibility of an average annual loss of production of twelve percent of yields from flooding, as well as 8.6 percent drought loss for maize, 4.3 percent drought loss for groundnuts, and 2.15 percent drought loss for all root crops. The model for the Shire Highlands area linear program for assistance is located below:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6228$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 86 – Shire Highlands Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	22467635.44
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables *P* used in the linear program:

Table 87 – Shire Highlands Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	589410.70
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables *F* used in the linear program:

Table 88 – Shire Highlands Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	26260.87
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 89 – Shire Highlands Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0394	0.2567	0	0.1041	0

The Shire Highlands area linear programming model for no available government assistance is listed below:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.6228$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables *C* used in the linear program:

Table 90 – Shire Highlands Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	23231141.15
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables *P* used in the linear program:

Table 91 – Shire Highlands Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	609440.33
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables F used in the linear program:

Table 92 – Shire Highlands Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	27153.28
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 93 – Shire Highlands Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1007	0

The Shire Highlands solutions were both below the weighted median for the area.

The next area studied is the Thyolo Mulanje Tea Estates area, located in the southern region of Malawi. It too struggles with occasional flooding concerns, and so the average annual loss from both drought and flood is 20.6 percent for maize, 16.3 percent for groundnuts, and 14.15 percent for all root crops. It is able to cultivate both an extra maize and potato crop because of its location. The following model explains the Thyolo Mulanje Tea Estates area linear programming model under years of government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5501$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 94 – Thyolo Mulanje Tea Estates Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	16143199.67
C_2	Caloric yield for one hectare of groundnuts	3352397.05
C_3	Caloric yield for one hectare of maize	1895739.27
C_4	Caloric yield for one hectare of potatoes	14978423.63
C_5	Caloric yield for one hectare of sweet potatoes	7704126.87

The following table offers the values of the variables *P* used in the linear program:

Table 95 – Thyolo Mulanje Tea Estates Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	137217.20
P_2	Protein yield for one hectare of groundnuts	152542.93
P_3	Protein yield for one hectare of maize	72082.18
P_4	Protein yield for one hectare of potatoes	392940.46
P_5	Protein yield for one hectare of sweet potatoes	140645.11

The following table offers the values of the variables *F* used in the linear program:

Table 96 – Thyolo Mulanje Tea Estates Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	28250.60
F_2	Fat yield for one hectare of groundnuts	290895.83
F_3	Fat yield for one hectare of maize	29758.70
F_4	Fat yield for one hectare of potatoes	17507.25
F_5	Fat yield for one hectare of sweet potatoes	4479.14

The following table offers the solution to the linear program:

Table 97 – Thyolo Mulanje Tea Estates Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0394	0.2567	0	0.1561	0

The subsequent section describes the Thyolo Mulanje Tea Estates area linear programming model for no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.5501$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 98 – Thyolo Mulanje Tea Estates Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	13041247.05
C_2	Caloric yield for one hectare of groundnuts	2924485.48
C_3	Caloric yield for one hectare of maize	1408596.18
C_4	Caloric yield for one hectare of potatoes	15487427.44
C_5	Caloric yield for one hectare of sweet potatoes	6985970.50

The following table offers the values of the variables P used in the linear program:

Table 99 – Thyolo Mulanje Tea Estates Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	110850.60
P_2	Protein yield for one hectare of groundnuts	133071.83
P_3	Protein yield for one hectare of maize	53559.41
P_4	Protein yield for one hectare of potatoes	406293.55
P_5	Protein yield for one hectare of sweet potatoes	127534.58

The following table offers the values of the variables F used in the linear program:

Table 100 – Thyolo Mulanje Tea Estates Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	22822.18
F_2	Fat yield for one hectare of groundnuts	253971.19
F_3	Fat yield for one hectare of maize	22111.68
F_4	Fat yield for one hectare of potatoes	18102.19
F_5	Fat yield for one hectare of sweet potatoes	4061.61

The following table offers the solution to the linear program:

Table 101 – Thyolo Mulanje Tea Estates Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0487	0.2941	0	0.1511	0

The Thyolo Mulanje Tea Estates area solutions are below the weighted median measure of land available.

The final region included in this study is the area of Western Rumphi and Mzimba. This area is located in the north of the country, and so only suffers from droughts. The average annual loss of production figures from droughts explain that there is a 6.7 percent loss of maize, a 3.35 percent loss of groundnuts, and a 1.675 percent loss of all root crops. This region does get to enjoy a second maize crop annually, but it is unable to cultivate more than one potato crop. The subsequent section explains the linear programming model for Western Rumphi and Mzimba under years of assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.7530$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 102 – Western Rumphi and Mzimba Area Calorie Yield under Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	18488993.68
C_2	Caloric yield for one hectare of groundnuts	3871077.36
C_3	Caloric yield for one hectare of maize	2227613.02
C_4	Caloric yield for one hectare of potatoes	8577481.09
C_5	Caloric yield for one hectare of sweet potatoes	8823625.80

The following table offers the values of the variables *P* used in the linear program:

Table 103 – Western Rumphi and Mzimba Area Protein Yield under Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	157156.45
P_2	Protein yield for one hectare of groundnuts	176144.26
P_3	Protein yield for one hectare of maize	84701.10
P_4	Protein yield for one hectare of potatoes	225019.63
P_5	Protein yield for one hectare of sweet potatoes	161082.47

The following table offers the values of the variables *F* used in the linear program:

Table 104 – Western Rumphi and Mzimba Area Fat Yield under Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	32355.74
F_2	Fat yield for one hectare of groundnuts	335903.01
F_3	Fat yield for one hectare of maize	34968.34
F_4	Fat yield for one hectare of potatoes	10025.63
F_5	Fat yield for one hectare of sweet potatoes	5130.01

The following table offers the solution to the linear program:

Table 105 – Western Rumphi and Mzimba Solution under Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0344	0.2223	0	0.2727	0

The last linear programming model presented in this research is the Western Rumphi and Mzimba area linear program for no government assistance:

$$\text{Minimize } f(X) = X_1 + X_2 + X_3 + X_4 + X_5$$

Subject to:

$$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \geq 3835125$$

$$P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 \geq 105922.5$$

$$F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5 \geq 78528.75$$

$$X_1 + X_2 + X_3 + X_4 + X_5 \leq 0.7530$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0$$

Where X_1 denotes hectares of cassava planted, X_2 denotes hectares of groundnuts planted, X_3 denotes hectares of maize planted, X_4 denotes hectares of potatoes planted, and X_5 denotes hectares of sweet potatoes planted. The following table offers the values of the variables C used in the linear program:

Table 106 – Western Rumphi and Mzimba Area Calorie Yield under No Assistance

Variable	Explanation	Value (calories per hectare)
C_1	Caloric yield for one hectare of cassava	14936291.39
C_2	Caloric yield for one hectare of groundnuts	3376959.63
C_3	Caloric yield for one hectare of maize	1655189.21
C_4	Caloric yield for one hectare of potatoes	8868965.07
C_5	Caloric yield for one hectare of sweet potatoes	8001112.98

The following table offers the values of the variables P used in the linear program:

Table 107 – Western Rumphi and Mzimba Area Protein Yield under No Assistance

Variable	Explanation	Value (grams of protein per hectare)
P_1	Protein yield for one hectare of cassava	126958.48
P_2	Protein yield for one hectare of groundnuts	153660.60
P_3	Protein yield for one hectare of maize	62935.68
P_4	Protein yield for one hectare of potatoes	232666.36
P_5	Protein yield for one hectare of sweet potatoes	146066.83

The following table offers the values of the variables F used in the linear program:

Table 108 – Western Rumphi and Mzimba Area Fat Yield under No Assistance

Variable	Explanation	Value (grams of fat per hectare)
F_1	Fat yield for one hectare of cassava	26138.51
F_2	Fat yield for one hectare of groundnuts	293265.42
F_3	Fat yield for one hectare of maize	25982.62
F_4	Fat yield for one hectare of potatoes	10366.32
F_5	Fat yield for one hectare of sweet potatoes	4651.81

The following table offers the solution to the linear program:

Table 109 – Western Rumphi and Mzimba Solution under No Assistance

Variables	X_1	X_2	X_3	X_4	X_5
Solution (hectares)	0.0425	0.2547	0	0.2639	0

The solutions for Western Rumphi and Mzimba are useful as they are below the weighted median land available. The regional solutions under government assistance for all areas are shown in detail in the table below:

Table 110 – Regional Solutions under Government Assistance

Region	Cassava	Groundnuts	Maize	Potato	Sweet Potato	Total
Chitipa, North and Central Karonga, Misuku Hills	0.0344	0.2223	0.0000	0.2727	0.0000	0.5294
Kasungu Lilongwe Plain	0.0344	0.2224	0.0000	0.1364	0.0000	0.3932
Lake Chirwa and Phalombe Plain	0.0394	0.2567	0.0000	0.1561	0.0000	0.4523
Lakeshore	0.0394	0.2567	0.0000	0.1561	0.0000	0.4523
Lower Shire	0.0394	0.2567	0.0000	0.1561	0.0000	0.4523
Middle Shire Valley	0.0394	0.2567	0.0000	0.1561	0.0000	0.4523
Nkhata Bay and South Karonga	0.0344	0.2223	0.0000	0.2727	0.0000	0.5294
Phirilongwe Hills	0.0394	0.2567	0.0000	0.1561	0.0000	0.4523
Rift Valley	0.0344	0.2224	0.0000	0.1364	0.0000	0.3932
Shire Highlands	0.0394	0.2567	0.0000	0.1041	0.0000	0.4002
Thyolo Mulanje Tea Estates	0.0394	0.2567	0.0000	0.1561	0.0000	0.4523
Western Rumphi and Mzimba	0.0344	0.2223	0.0000	0.2727	0.0000	0.5294

There were four types of crop solutions offered under assistance, which were tied to the area of the country in which the region was located and the number of potato crops cultivated annually: planting a total of 0.5294 hectares in the northern regions, 0.4523 hectares in the southern regions with two potato crops, 0.4002 hectares in the Shire

Highlands (the only southern region with three potato crops), and 0.3932 hectares in the central regions. The central regions required the least area for planting as they were able to cultivate two potato crops per year, but escaped the threat of flood plaguing the southern regions. The southern regions required the second and third most area for planting as they are able to either realize two or three potato crops per year, but lost a greater amount of their crop to flooding. The northern regions required the most land area because they were only able to harvest one potato crop per year without irrigation (it was assumed that farmers had no access to irrigation). None of the plans recommended planting either maize or sweet potato, despite the possibility of a second annual maize crop in every area, much like the national plan under assistance. Again, this recommendation will be slightly controversial.

The regional solutions under no government assistance are offered below:

Table 111 – Regional Solutions under No Government Assistance

Region	Cassava	Groundnuts	Maize	Potato	Sweet Potato	Total
Chitipa, North and Central Karonga, Misuku Hills	0.0425	0.2547	0.0000	0.2639	0.0000	0.5610
Kasungu Lilongwe Plain	0.0425	0.2548	0.0000	0.1320	0.0000	0.4293
Lake Chirwa and Phalombe Plain	0.0487	0.2941	0.0000	0.1511	0.0000	0.4938
Lakeshore	0.0487	0.2941	0.0000	0.1511	0.0000	0.4938
Lower Shire	0.0487	0.2941	0.0000	0.1511	0.0000	0.4938
Middle Shire Valley	0.0487	0.2941	0.0000	0.1511	0.0000	0.4938
Nkhata Bay and South Karonga	0.0425	0.2547	0.0000	0.2639	0.0000	0.5610
Phirilongwe Hills	0.0487	0.2941	0.0000	0.1511	0.0000	0.4938
Rift Valley	0.0425	0.2548	0.0000	0.1320	0.0000	0.4293
Shire Highlands	0.0487	0.2941	0.0000	0.1007	0.0000	0.4435
Thyolo Mulanje Tea Estates	0.0487	0.2941	0.0000	0.1511	0.0000	0.4938
Western Rumphi and Mzimba	0.0425	0.2547	0.0000	0.2639	0.0000	0.5610

Under no assistance, the solutions change to accommodate the lower yields. There were four solutions for the regions: planting a total of 0.5610 hectares in the north, 0.4938 hectares in the south with two potato crops, 0.4435 hectares in the Shire Highlands, and 0.4293 hectares in the central regions. The plan for assistance required the cultivation of fewer hectares of the crops in all but two instances. In the central region the no assistance plan recommended planting fewer potatoes than the assistance plan, and in the two-potato crop southern regions the plan for assistance asked farmers to plant more potatoes than the plan for no assistance. The central regions under no assistance were once again the regions with the smallest recommended planting area, likely due to the cultivation of the second potato crop without the threat of flooding. The Lakeshore region is a special case as it spans two regions of the country, both northern and southern, but it is able to cultivate a second potato crop. The resulting plan for the Lakeshore region follows a normal plan for any region in the southern part of the country as there is a risk of flooding along the lakeshore (even in the north) and the southern region has the highest loss from drought. Since this planning strategy is meant to maximize security under the worst conditions, the plan for the region must be focused on the southern portion of the lakeshore. The southern regions – again, depending on potato cultivation – are recommended to plan for either second or third lowest total cultivation. Again, the northern regions have the highest recommended area for cultivation as they are able to cultivate only one potato crop per year. Like the national plan, none of the regional plans recommend planting either maize or sweet potato under no assistance, even though two maize crops per year are possible.

The shadow prices, or marginal costs of capital stocks in this analysis were all very low values, much less than one. Thie describes shadow prices for linear programs in his book, and explains that the dual to a maximization problem is a minimization problem, and that the solution has variables which are competitive shadow prices (Thie, 2008: 166). The shadow prices explain the change in the optimal value of the objective function for an extra unit of resource, or the opportunity cost of an unused good (Thie, 2008: 166). All of the nonzero shadow prices reported from the linear programs were decimal values to the millionths place.

5.4: Factor Volatility

For all of the linear programs, regional or national, assistance or no, the most volatile factor was fat. This was determined using the percent difference of the nutritional yield attained under the chosen plan's opposing strategy. Nationally, if a farmer planned for assistance, but the government offered none, they saw a deficit of 0.1953 percent of their annual caloric requirements, a deficit of 0.7498 percent of their annual protein requirements, or a deficit of 10.3676 percent of their annual fat requirements, see the table below.

Table 112 – National Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3827636.87	3835125	-0.1953
Protein	105128.35	105922.5	-0.7498
Fat	70387.24	78528.75	-10.3676

Since roughly ten percent of the yearly fat for the household was on the line if the wrong strategy was chosen, as opposed to one percent of protein or two-tenths of a percent of calories, this was seen as the most important factor. Nationally, if the farmer planned for no assistance and the government offered them assistance, surpluses were realized.

Table 113 – National Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3872447.10	3835125	0.9732
Protein	107575.00	105922.5	1.5601
Fat	87708.60	78528.75	11.6898

There was a surplus of 0.9732 percent of total required calories, a surplus of 1.5601 percent of total required protein, and a surplus of 11.6898 percent of required fat. Again, fat was the factor with the greatest gain over calories and protein.

The same conclusion was reached regionally. For all regions when a farmer planned for assistance and received none, the caloric deficit was 3.9767 percent, the protein deficit was 3.3710 percent, and the fat deficit was 12.2256 percent. For all regions when a farmer planted for no assistance and received some, the caloric surplus was 0.9732 percent, the protein surplus was 1.5601 percent, and the fat surplus was 11.6898 percent. Regionally fat was determined to be the most volatile factor. The collection of tables from each type of scenario in each of the twelve areas is included below:

Table 114 – Chitipa, North and Central Karonga, and Misuku Hills Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 115 – Chitipa, North and Central Karonga, and Misuku Hills Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 116 – Kasungu Lilongwe Plain Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 117 – Kasungu Lilongwe Plain Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 118 – Lake Chirwa and Phalombe Plain Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 119 – Lake Chirwa and Phalombe Plain Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 120 – Lakeshore Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 121 – Lakeshore Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 122 – Lower Shire Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 123 – Lower Shire Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 124 – Middle Shire Valley Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 125 – Middle Shire Valley Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 126 – Nkhata Bay and South Karonga Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 127 – Nkhata Bay and South Karonga Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 128 – Phirilongwe Hills Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 129 – Phirilongwe Hills Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 130 – Rift Valley Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 131 – Rift Valley Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 132 – Shire Highlands Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 133 – Shire Highlands Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 134 – Thyolo Mulanje Tea Estates Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 135 – Thyolo Mulanje Tea Estates Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

Table 136 – Western Rumphi and Mzimba Variable Volatility for the Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	3682615.06	3835125	-3.9767
Protein	101970.56	105922.5	-3.3710
Fat	68928.13	78528.75	-12.2256

Table 137 – Western Rumphi and Mzimba Variable Volatility for the No Assistance Plan

Variable	Yield under Opposing Conditions	Constraint Value	Percent Difference
Calories	4035038.42	3835125	0.9732
Protein	110913.83	105922.5	1.5601
Fat	89561.09	78528.75	11.6898

5.5: Game Theory Results

After finding that the most volatile factor, the two-by-two payoff matrices of the game models were then populated with fat yield data and the minimax criterion was used to evaluate them. The first game to be evaluated is the game using national level data:

Table 138 – National Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	70387.24
Farmer Strategy – Plan for No Government Assistance	87708.60	78528.75

Nationally, the minimax criterion determined that the most secure option for the farmer was to plan for no assistance, because otherwise there would be a serious deficit should the government not offer assistance and the farmer have already planned for it. If the farmer plans on not having government assistance, then the worst-case scenario is that the farmer meets all of their needs and is food secure. If the government does choose to offer assistance, the farmer has a surplus of food which they could save for future use, sell, or give to food insecure relatives.

Regionally, the same conclusions about the optimal strategy for use were reached in all twelve areas. In order to ensure food security in these regions it is recommended that farmers exercise the plan for no government assistance to protect themselves against the potential fat deficit from following the plan for assistance in non-assistance years. The specific area games are collected and displayed below:

Table 139 – Chitipa, North and Central Karonga, and Misuku Hills Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 140 – Kasungu Lilongwe Plain Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 141 – Lake Chirwa and Phalombe Plain Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 142 – Lakeshore Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 143 – Lower Shire Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 144 – Middle Shire Valley Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 145 – Nkhata Bay and South Karonga Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 146 – Phirilongwe Hills Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 147 – Rift Valley Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 148 – Shire Highlands Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 149 – Thyolo Mulanje Tea Estates Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

Table 150 – Western Rumphi and Mzimba Area Game

Resulting Fat (g) per Hectare	Government Strategy – Offer Assistance to Farmers	Government Strategy – Offer No Assistance to Farmers
Farmer Strategy – Plan for Government Assistance	78528.75	68928.13
Farmer Strategy – Plan for No Government Assistance	89561.09	78528.75

According to the minimax criterion the smallholder farmers of Malawi should plan for no assistance from the government to maximize their chances for food security regionally. If the farmer plans for assistance and receives assistance, he has met the needs of his household for the year. Likewise if the farmer plans for no assistance and receives none, his needs are met, which is his worst case scenario from the plan for no government assistance. However, if the farmer plans for assistance and receives none, they are experiencing a deficit of roughly twelve percent of their annual fat requirement, which is the worst case scenario for following that planning strategy. If the farmer plans for no government assistance, but receives assistance he experiences a surplus of about eleven percent of his annual fat requirement. This surplus could be stored for use later by drying the crops and turning them into flour, which is a method preferred by many households for food preparation, or sold to help supplement income. The regional linear programs differed from the national linear program in terms of space, mostly from the effect of regional crop issues on yields, but both the regional and national games under the minimax criterion pointed to the plan for no assistance as the most secure strategy. Caution is suggested in the Lower Shire region, however, due to the land area requirements for the plan and the weighted median land requirements of the area. The plan for no assistance in this region requires 104.3 percent of the calculated weighted median land available to farmers, so it would work for a number of people, but not a majority. Further research into this specific area is required to come up with a plan that would work for a larger number of people.

5.6: Limitations to the Study

There are some limitations to this study that should be addressed for the future. First, this study focuses on keeping people alive in the short term – getting them the appropriate number of calories, fats, and protein – and so does not consider micronutrients as a component of this plan – several of the B vitamins, vitamin C, folic acid, vitamin A, and other important micronutrients. The decision to exclude micronutrients was based on time constraints, but is something worth looking into in the future. That being said, the crops chosen for this study are the crops grown most frequently in Malawi, so any micronutrient deficit from eating these crops may already be an issue for some of the population. For example, the current diet of Malawi consists mainly of maize, which contains no vitamin D and no vitamin B12, according to the USDA nutrient database (USDA, 2015). Potatoes contain more vitamin B6, vitamin K, and Vitamin C than maize per 100 grams, but would still require some micronutrient supplements to reach recommended daily values (USDA, 2015).

Another limitation is that it is assumed that the food preparation will be the same, and that the nutrient values for the crops will be the same after cooking. The USDA figures used are based on the calorie, protein, and fat content of raw foods, and it was assumed that food preparation would not significantly change the nutritional values of the foods, although there are certain ways to prepare foods that can decrease the nutritional values of those foods. Along with cooking not changing the nutrient value of the crops, another limitation arises from the assumption that all crops have the same nutritional value across all areas. It is also assumed that all plots of land will yield the same amount of product from the same amount of inputs across Malawi. This decision was made based on the lack of data about agricultural inputs apart from the assistance offered by the government, and lack of data about soil quality and productivity.

Crop losses from severe droughts were not examined in this study, although the more severe droughts or floods would reduce the crop yield more than the average annual value. The decision to exclude further losses due to climatic events like severe droughts was made partly due to a lack of reliable data and constraints on the time of this research, as well as this study wanting to focus on the presence or absence of government assistance and not climatic factors beyond the average. Extensions of this research which include losses for certain droughts or suggest a plan for a worst case scenario which focus more on climatic aspects and their effects on yields would be useful to do in the future. A further limitation to this study is that it looks specifically at staple crops and does not take into account other segments of food supply, like raising farm animals or fishing. In the regions bordering Lake Malawi, fishing is possible, and raising farm animals is possible in every region. These strategies can also increase the food security of a household, and are not examined in this analysis due to time and data constraints, but this would be one of the next steps in expanding on this research.

The figures for landholdings in this study came from a dataset which was unable to explain if the land being cultivated by each household was the total land available to plant for the household, which is a limitation. Future research may be to do another survey of the areas and adjust the landholding estimates based on how much total land is available to a household. Other opportunities for future work with datasets like this kind would be to determine if the plot a household owns or has access to for planting changes over time, as well as how this plot will be passed down within the family. If the family chooses to split this land up among several people, the resulting plot may be too small for these plans to be effective in the future.

5.7: Food Crop Percentage of Land Cultivated

NASFAM and Future Agricultures had championed the idea that sixty percent of land cultivated by a smallholder farmer should be set aside for food crops, and the remaining forty percent should be devoted to cash crops (NASFAM, 2015; Chirwa and Matita, 2012: 3). According to the results of this study, the ideal percentage of food crop cultivation depends largely on the region being examined. Under assistance nationally, this recommendation was determined to be ideal as the percentage of land allocated to food crops found by the linear program was 59.4 percent of the national average landholding of 0.88 hectares. Nationally, if no assistance is planned for, 61.0 percent of the average landholding is needed for food crop cultivation. The NASFAM recommendation in this case is fairly accurate.

Unfortunately, when individual regions are examined the NASFAM recommendations are inappropriate considering the weighted median measure of land available in each region. See the table below for the percentages by region under assistance:

Table 151 – Food Crops as a Percentage of Land Cultivated under Assistance

Region	Solution Total (Hectares)	Weighted Median (Hectares)	Difference (Hectares)	Percentage of Land Devoted to Food Crop Cultivation
Chitipa, North and Central Karonga, Misuku Hills	0.5294	0.616513	0.087128	85.86765
Kasungu Lilongwe Plain	0.3932	0.802747	0.40954	48.98265
Lake Chirwa and Phalombe Plain	0.4523	0.513543	0.061289	88.0655
Lakeshore	0.4523	0.58866	0.136406	76.82777
Lower Shire	0.4523	0.473284	0.02103	95.55664
Middle Shire Valley	0.4523	0.599332	0.147077	75.45976
Nkhata Bay and South Karonga	0.5294	0.641359	0.111974	82.54114
Phirilongwe Hills	0.4523	0.674098	0.221843	67.09033
Rift Valley	0.3932	0.591613	0.198413	66.46237
Shire Highlands	0.4002	0.622774	0.222569	64.26169
Thyolo Mulanje Tea Estates	0.4523	0.550074	0.09782	82.21699
Western Rumphi and Mzimba	0.5294	0.753036	0.22365	70.30016

Under the condition of assistance regionally, only one region was below the NASFAM recommended sixty percent guideline – Kasungu Lilongwe Plain – and the plan in this area only takes up about half of the available weighted median land. The NASFAM recommendation in this area is not appropriate because while it does not limit the crop planning strategy from being cultivated, NASFAM is recommending ten additional percent of land be allocated to food cultivation, which it does not need to be. The other eleven regions were above the recommended sixty percent guideline, with three regions in the mid-sixties, three regions in the seventies, four regions in the eighties, and the Lower Shire region requiring 95.5 percent of cultivated land going towards food crops in order to meet the recommended nutritional guidelines for a family of five with some environmental restrictions on yield taken into account. Should these families plant only sixty percent of their land with food crops they will not attain food self-sufficiency, and could not adequately follow the crop planning strategy for years of assistance.

Under conditions of no assistance offered from the government, the resulting percentages of food crops cultivated are higher in every instance, as would be expected.

Table 152 - Food Crops as a Percentage of Land Cultivated under No Assistance

Region	Solution Total (Hectares)	Weighted Median (Hectares)	Difference (Hectares)	Percentage of Land Devoted to Food Crop Cultivation
Chitipa, North and Central Karonga, Misuku Hills	0.5610	0.616513	0.0555	91.0019
Kasungu Lilongwe Plain	0.4293	0.802747	0.3735	53.4758
Lake Chirwa and Phalombe Plain	0.4938	0.513543	0.0197	96.1649
Lakeshore	0.4938	0.58866	0.0948	83.8936
Lower Shire	0.4938	0.473284	-0.0206	104.3450
Middle Shire Valley	0.4938	0.599332	0.1055	82.3998
Nkhata Bay and South Karonga	0.5610	0.641359	0.0803	87.4765
Phirilongwe Hills	0.4938	0.674098	0.1802	73.2607
Rift Valley	0.4293	0.591613	0.1623	72.5643
Shire Highlands	0.4435	0.622774	0.1793	71.2101
Thyolo Mulanje Tea Estates	0.4938	0.550074	0.0562	89.7785
Western Rumphi and Mzimba	0.5610	0.753036	0.1920	74.5036

The Kasungu Lilongwe Plain region once again was under NASFAM's recommended sixty percent guideline, this time at 53.5 percent of food crops planted. The rest of the regions are well over NASFAM's suggested sixty percent, with four regions in the seventies, four regions in the eighties, and two regions in the ninety percentage ranges. The plan of one region, the Lower Shire, was unable to satisfy all the constraints of the linear program in a space less than the weighted median of the region. The plan could still be useful for the smallholder farmers who cultivate more than 0.4938 hectares, but there are a majority of smallholder farmers in this area who would not be helped by the plan at their current level of cultivation. Options for farmers of this area would be to cultivate more area if they are able to as the landholdings data used here described the area that was cultivated, instead of the area that was available to be cultivated. It is also recommended that the government offer assistance to farmers in this area every year, even if assistance is not offered nationally, so that the farmers can always count on the assistance and use the assistance plan without worrying about a nutrient deficit. The NASFAM plan would not be appropriate for the twelve regions studied here according to these results. This study’s recommendation would be to encourage regionally specific ideal crop percentages instead of having one national percentage.

Chapter 6

Conclusion

6.1: Conclusions, Recommendations, and Opportunities for Further Study

Food security problems will continue to plague Malawi for much of the near future should they continue with their current agricultural practices. The research presented here is meant to serve as a guide for future efforts to increase the food security of the country by using national scale data and applying it to several regions in Malawi under instances of government offered assistance, and absence of that assistance. Problems relating to modern famine and food security would benefit from being included in the hazards literature for further analysis. Studies of efforts of mitigation in areas struggling with modern famine, like Malawi, would be beneficial to other areas without such strategies in place, just as the studies from Nyeko (2009) and Teklu (1994) about the success of crop planning strategies in other areas was useful here. Regional plot size data in Malawi, while containing some issues related to data collection, was determined to be dependent through a Chi-Square analysis. This data, along with potato crop data, average annual drought loss by region, and average annual flood loss by region, allowed for the use of regional analysis of the linear program designed to help improve food security.

The linear programs showed that food security was possible in twenty-three out of twenty-four situations throughout Malawi. It recommended several crop planning strategies for use throughout the country, and was effective as a tool in creating a mitigation strategy for modern famine. The plan also showed that there was a significant difference between the plan for government offered assistance years and years in which the farmers are not able to rely on the government for aid. The area where the plan was not effective, the Lower Shire region under years of no government assistance, requires further study to create an effective plan. One policy recommendation based on this research for the government of Malawi would be to ensure assistance to the Lower Shire region for every year, regardless of the status of national assistance packages. This would allow the region to plant the plan for assistance, which is possible to plant in this area given the weighted median land available. Once the linear programming results were found, each plan was then analyzed to find the most volatile constraint for use in the two-person non-zero sum games for each region. Fat was determined in all instances to be the most volatile factor. The resulting two-person non-zero sum games were then analyzed using the minimax criterion, and in every case the crop planning strategy for no government assistance was found to be the optimal strategy.

The linear programming results for the optimal solution to the crop planning strategy was then compared to the weighted median land available in every region so a percentage of food crops could be determined, and then compared to the NASFAM recommendation. Nationally the NASFAM recommendation would work considering the average smallholder farmer holding reported by the government, but for every one of the twelve specific regions in both assistance situations, the NASFAM recommendation was not ideal. The NASFAM recommendation should be specified by region to be able to advise the most farmers, and desperately needs to be recalculated both nationally and regionally.

While some of the recommendations here may seem controversial, especially considering the abandonment of maize planting altogether, the aim is to offer a plan for food security which will work for the maximum number of people, and in that respect this research has accomplished its goal. Further study is required in several areas, especially for regions of the country not included in this study for absence of data. The next step in this research is for the planning strategy presented here to be tested in the study area. The inclusion of other effects on yield, like climate effects or other things which have not been covered in this research due to time constraints, would be beneficial to further this research in the future. This study did not address the concerns of future climate change and the resulting crop yields as the main focus here was on the difference between government offered assistance and a lack of government assistance for smallholder farmers. This study determined that there was a difference between assistance and no assistance in total area planted. In addition, the effects of planting one strategy and the government giving the opposite strategy resulted in roughly one-tenth of the recommended amount of annual fat for a household either as a deficit or a surplus. The minimax criterion determined that the best course of action was to plan for no assistance, so the worst case scenario was to meet the needs of the household. The adoption of this strategy has the potential to reduce the amount of food insecurity in Malawi, and has therefore accomplished its goal.

The content analysis was instrumental in answering the first research question. It determined that crop planning strategies can be seen as a form of mitigation against famine, but is seldom used in the research as the papers discussing specific crop planning strategies made up fewer than ten percent of the responses to the famine mitigation inquiry. The national level linear programs answered the second research question, presenting a mix of staple crops that offer a somewhat diversified diet for a household of five in Malawi, and the subsequent game theory analysis determined the best plan to use to maximize the household's food security. This national plan was then modified so it could be adapted to twelve regions in Malawi in order to answer the fourth research question: Can a discussion of regional issues help to adapt the national planting strategy for specific regions in Malawi? The addition of regional issues like plot size, potato production potential, flood loss and drought loss was able to adapt the national plan and make alternate, regionally specific plans for twelve regions under either government assistance or a lack of assistance. The third research question was answered by comparing the NASFAM recommendation with the linear programming solutions. It was found that an ideal percentage of food crops to cash crops would have to be determined for each region in order to be effective, as the NASFAM plan was effective if examined nationally, but not regionally. This study has successfully answered all research questions, and should now be tested in a real world environment.

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Appendix A

Table A1 – Crop Quantity Produced in Metric Tons

Year	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
1983	143686	53991	1369403	[..]	[..]
1984	258693	54766	1397948	[..]	59926
1985	209321	62240	1355202	[..]	81047
1986	218282	88297	1294564	[..]	80003
1987	169403	88073	1201757	13180	121195
1988	134785	76754	1423848	11400	101974
1989	154762	34752	1509513	11979	177424
1990	144760	18574	1342809	34200	94911
1991	167818	31051	1589377	39969	176999
1992	128827	12060	657000	49144	43074
1993	216005	31785	2033957	47975	210572
1994	250056	30654	818999	42495	165322
1995	328424	30664	1225580	79500	317714
1996	534549	40327	1242588	106422	596469
1997	713876	68718	1233538	116884	858129
1998	829821	97228	1292669	120338	1432383
1999	895420	124604	2245824	160088	1680303
2000	2757186	116551	2290018	160251	1877032
2001	3313126	147729	1589437	323217	2528790
2002	151279207	150604	1485272	348975	105482934
2003	1703355	179326	1847476	398806	1485391
2004	2532079	153414	1608349	420590	1762034
2005	2197640	141078	1225234	404420	1081463
2006	2832141	203071	1624030	527831	1781595
2007	3238943	261810	1686442	593842	2264969
2008	3491183	243215	1596955	673122	2320696
2009	3823236	275176	1608945	775283	2652481
2010	4000986	297487	3419409	775650	2897888
2011	4316373	325215	3895181	928941	3223263
2012	4692202	368081	3618699	976735	3582428
2013	4813699	380800	3639866	963618	3572337

Table A2 – Crop Area Planted in Hectares

Year	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
1983	59351	146314	681	[..]	[..]
1984	81497	144935	1182601	[..]	21340
1985	80262	135966	1144853	[..]	22717
1986	72904	176293	1193275	[..]	22447
1987	64875	209938	1182415	3200	28977
1988	61780	175819	1215087	3080	28517
1989	72823	139691	1270822	3437	43823
1990	61506	48185	1343784	4460	29839
1991	71619	69978	1391878	5565	48384
1992	63965	64386	1368093	5855	19886
1993	75050	61040	1327038	6217	34466
1994	72149	95309	1129327	3844	37151
1995	94731	89373	1225580	7782	60701
1996	116523	71586	875195	9042	68804
1997	125813	100140	1233538	10113	91700
1998	151941	140747	1292669	12851	135346
1999	166125	170004	1369153	13900	150120
2000	180758	169078	1435222	14310	163524
2001	198470	181337	1446264	22786	187897
2002	101408	198306	1513945	25804	84930
2003	110196	218760	1617917	30338	113586
2004	154945	207786	1478750	33053	147519
2005	153687	248276	1513929	35439	128982
2006	163598	244567	1762839	40601	132461
2007	172539	258111	1215356	40191	147985
2008	183014	266115	1596955	45816	159227
2009	188418	266946	1608996	48312	163379
2010	195828	295236	1696270	48805	179933
2011	200139	308094	1732371	52689	188705
2012	209583	353190	1732859	54536	204249
2013	211089	362824	1676758	54538	204047

Table A3 – Crop Yield in Kilograms per Hectare

Year	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
1983	2420.95331	369.0077505	2010870.778	[…]	[…]
1984	3174.26408	377.8659399	1182.096075	[…]	2808.153702
1985	2607.97139	457.7614992	1183.734506	[…]	3567.680592
1986	2994.10183	500.8536924	1084.8832	[…]	3564.084287
1987	2611.22158	419.5190961	1016.358047	4118.75	4182.455051
1988	2181.6931	436.551226	1171.807451	3701.298701	3575.902093
1989	2125.18023	248.7776593	1187.824101	3485.306954	4048.650252
1990	2353.59152	385.4726575	999.274437	7668.161435	3180.770133
1991	2343.20502	443.7251708	1141.893902	7182.210243	3658.213459
1992	2014.02329	187.3077998	480.2305106	8393.509821	2166.046465
1993	2878.1479	520.7241153	1532.704414	7716.74441	6109.557245
1994	3465.82766	321.6275483	725.2097931	11054.89074	4450.001346
1995	3466.91157	343.1013841	1000	10215.88281	5234.081811
1996	4587.49775	563.3364066	1419.784162	11769.74121	8669.10354
1997	5674.10363	686.219293	1000	11557.7969	9358.004362
1998	5461.4686	690.7998039	1000	9364.096179	10583.1203
1999	5390.03762	732.9474601	1640.301705	11517.1223	11193.06555
2000	15253.466	689.332734	1595.584516	11198.53249	11478.63311
2001	16693.334	814.6655123	1098.995066	14184.89423	13458.38411
2002	1491787.7	759.4525632	981.0607387	13524.06604	1241998.516
2003	15457.503	819.7385262	1141.885523	13145.42818	13077.23663
2004	16341.7922	738.3269325	1087.640913	12724.71485	11944.45461
2005	14299.4528	568.2305176	809.3074378	11411.72155	8384.604053
2006	17311.5869	830.3287034	921.2582658	13000.44334	13449.95886
2007	18772.237	1014.331044	1387.611531	14775.497	15305.39582
2008	19076.0434	913.9469778	1000	14691.85437	14574.76433
2009	20291.2461	1030.830205	999.9683032	16047.42093	16235.14038
2010	20431.1232	1007.624409	2015.840049	15892.83885	16105.37256
2011	21566.876	1055.570702	2248.46814	17630.64397	17080.96235
2012	22388.2758	1042.161443	2088.282428	17909.91272	17539.51305
2013	22804.1205	1049.544683	2170.775986	17668.74473	17507.42231

Table A4 – Yield during Years of Government Assistance

Year	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
1987	2611.222	419.5191	1016.358	4118.75	4182.455
1988	2181.693	436.5512	1171.807	3701.299	3575.902
1989	2125.18	248.7777	1187.824	3485.307	4048.65
1990	2353.592	385.4727	999.2744	7668.161	3180.77
1991	2343.205	443.7252	1141.894	7182.21	3658.213
1992	2014.023	187.3078	480.2305	8393.51	2166.046
1993	2878.148	520.7241	1532.704	7716.744	6109.557
1999	5390.038	732.9475	1640.302	11517.12	11193.07
2000	15253.47	689.3327	1595.585	11198.53	11478.63
2006	17311.59	830.3287	921.2583	13000.44	13449.96
2007	18772.24	1014.331	1387.612	14775.5	15305.4
2008	19076.04	913.947	1000	14691.85	14574.76
2009	20291.25	1030.83	999.9683	16047.42	16235.14
2010	20431.12	1007.624	2015.84	15892.84	16105.37
2011	21566.88	1055.571	2248.468	17630.64	17080.96
2012	22388.28	1042.161	2088.282	17909.91	17539.51
2013	22804.12	1049.545	2170.776	17668.74	17507.42
Average	11752.48	706.3939	1388.128	11329.35	10434.81

Table A5 – Average Nutritional Yield during Years of Assistance

Crop	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
Average Yield (Kilograms per Hectare)	11752.48	706.3939	1388.128	11329.35	10434.81
Average Caloric Yield (Calories per Hectare)	18803960	4005253	1193790	8723601	8973939
Average Protein Yield (Grams per Hectare)	159833.7	182249.6	45391.8	228852.9	163826.6
Average Fat Yield (Grams per Hectare)	32906.93	347545.8	18739.73	10196.42	5217.407

Table A6 – Yield during Years of No Government Assistance

Year	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
1994	3465.8277	321.6275	725.2098	11054.89	4450.0013
1995	3466.9116	343.1014	1000	10215.88	5234.0818
1996	4587.4977	563.3364	1419.784	11769.74	8669.1035
1997	5674.1036	686.2193	1000	11557.8	9358.0044
1998	5461.4686	690.7998	1000	9364.096	10583.12
2001	16693.334	814.6655	1098.995	14184.89	13458.384
2003	15457.503	819.7385	1141.886	13145.43	13077.237
2004	16341.792	738.3269	1087.641	12724.71	11944.455
2005	14299.453	568.2305	809.3074	11411.72	8384.6041
Average	9494.2101	616.2273	1031.425	11714.35	9462.1101

Table A7 – Average Nutritional Yield during Years of No Assistance

Crop	Cassava	Groundnuts, with shell	Maize	Potatoes	Sweet potatoes
Average Yield (Kilograms per Hectare)	9494.2101	616.2273	1031.425	11714.35	9462.1101
Average Caloric Yield (Calories per Hectare)	15190736	3494009	887025.3	9020051	8137414.7
Average Protein Yield (Grams per Hectare)	129121.26	158986.6	33727.59	236629.9	148555.13
Average Fat Yield (Grams per Hectare)	26583.788	303430.3	13924.23	10542.92	4731.055

Table A8 – Household Plot Size

Region	(%) Less than 0.5 acres	(%) 0.5 to 1 acres	(%) 1 to 2 acres	(%) 2 to 4 acres	(%) 4 acres or more	(%) Did not cultivate	HH interviewed
Chitipa, North and Central Karonga, Misuku Hills	3.9	31.4	44.7	18	1.2	0.8	265
Kasungu Lilongwe Plain	3.1	20.3	40.3	26.9	9	0.3	1,003
Lake Chirwa and Phalombe Plain	12.5	40.5	31.1	10.9	2.5	2.5	533
Lakeshore	11.9	30.9	36.7	14	4	2.5	290
Lower Shire	12.3	48.8	24.8	9.3	2.1	2.7	399
Middle Shire Valley	12.1	28.5	37.3	18.9	2.2	1.1	371
Nkhata Bay and South Karonga	4.3	32.4	42.8	15.5	4.7	0.4	288
Phirilongwe Hills	11.4	23.4	36.7	22.2	5.1	1.3	159
Rift Valley	13.3	30.8	35.6	14.2	4.8	1.2	345
Shire Highlands	8	31.3	37.7	17.4	3.8	1.8	509
Thyolo Mulanje Tea Estates	18.4	36.2	25.8	13.2	5.8	0.8	375
Western Rumphi and Mzimba	6	23.5	38.3	22.4	9	0.8	371

Table A9 – Calculated Number of Households per Category

Region	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 4 acres	4 acres or more	Did Not Cultivate	Total
Chitipa, North and Central Karonga, Misuku Hills	10.335	83.21	118.455	47.7	3.18	2.12	265
Kasungu Lilongwe Plain	31.093	203.609	404.209	269.807	90.27	3.009	1001.997
Lake Chirwa and Phalombe Plain	66.625	215.865	165.763	58.097	13.325	13.325	533
Lakeshore	34.51	89.61	106.43	40.6	11.6	7.25	290
Lower Shire	49.077	194.712	98.952	37.107	8.379	10.773	399
Middle Shire Valley	44.891	105.735	138.383	70.119	8.162	4.081	371.371
Nkhata Bay and South Karonga	12.384	93.312	123.264	44.64	13.536	1.152	288.288
Phirilongwe Hills	18.126	37.206	58.353	35.298	8.109	2.067	159.159
Rift Valley	45.885	106.26	122.82	48.99	16.56	4.14	344.655
Shire Highlands	40.72	159.317	191.893	88.566	19.342	9.162	509
Thyolo Mulanje Tea Estates	69	135.75	96.75	49.5	21.75	3	375.75
Western Rumphi and Mzimba	22.26	87.185	142.093	83.104	33.39	2.968	371

Table A10 – Rounded Number of Households per Category

Region	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 4 acres	4 acres or more	Did Not Cultivate	Total
Chitipa, North and Central Karonga, Misuku Hills	10	83	119	48	3	2	265
Kasungu Lilongwe Plain	31	204	404	270	91	3	1003
Lake Chirwa and Phalombe Plain	67	216	166	58	13	13	533
Lakeshore	34	90	106	41	12	7	290
Lower Shire	49	195	99	37	8	11	399
Middle Shire Valley	45	106	138	70	8	4	371
Nkhata Bay and South Karonga	12	93	123	45	14	1	288
Phirilongwe Hills	18	37	59	35	8	2	159
Rift Valley	46	106	123	49	17	4	345
Shire Highlands	41	159	192	89	19	9	509
Thyolo Mulanje Tea Estates	69	136	97	49	21	3	375
Western Rumphi, Mzimba	22	87	142	83	34	3	371

Table A11 – Weighted Median Hectares by Region

Region	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 4 acres	4 acres or more	Total	Weighted Medians acres	Weighted medians hectares
Chitipa, North and Central Karonga, Misuku Hills	10	83	119	48	3	263	1.523436	0.616513
Kasungu Lilongwe Plain	31	204	404	270	91	1000	1.983629	0.802747
Lake Chirwa and Phalombe Plain	67	216	166	58	13	520	1.268992	0.513543
Lakeshore	34	90	106	41	12	283	1.454609	0.58866
Lower Shire	49	195	99	37	8	388	1.169509	0.473284
Middle Shire Valley	45	106	138	70	8	367	1.48098	0.599332
Nkhata Bay and South Karonga	12	93	123	45	14	287	1.584832	0.641359
Phirilongwe Hills	18	37	59	35	8	157	1.66573	0.674098
Rift Valley	46	106	123	49	17	341	1.461907	0.591613
Shire Highlands	41	159	192	89	19	500	1.538906	0.622774
Thyolo Mulanje Tea Estates	69	136	97	49	21	372	1.359261	0.550074
Western Rumphi, Mzimba	22	87	142	83	34	368	1.86079	0.753036

Table A12 – Chi Square Observed Counts Data

Region	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 4 acres	4 acres or more	Total HH Cultivating Land	HH that Did Not Cultivate	Total HH in Survey
Chitipa, North and Central Karonga, Misuku Hills	10	83	119	48	3	263	2	265
Kasungu Lilongwe Plain	31	204	404	270	91	1000	3	1003
Lake Chirwa and Phalombe Plain	67	216	166	58	13	520	13	533
Lakeshore	34	90	106	41	12	283	7	290
Lower Shire	49	195	99	37	8	388	11	399
Middle Shire Valley	45	106	138	70	8	367	4	371
Nkhata Bay and South Karonga	12	93	123	45	14	287	1	288
Phirilongwe Hills	18	37	59	35	8	157	2	159
Rift Valley	46	106	123	49	17	341	4	345
Shire Highlands	41	159	192	89	19	500	9	509
Thyolo Mulanje Tea Estates	69	136	97	49	21	372	3	375
Western Rumphi, Mzimba	22	87	142	83	34	368	3	371
Total	444	1512	1768	874	248	4846	62	4908

Table A13 – Expected Value Frequency Table

Region	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 4 acres	4 acres or more	Total
Chitipa, North and Central Karonga, Misuku Hills	24.09657	82.05861	95.95213	47.43335	13.45935	263
Kasungu Lilongwe Plain	91.62196	312.0099	364.837	180.3549	51.17623	1000
Lake Chirwa and Phalombe Plain	47.64342	162.2452	189.7152	93.78456	26.61164	520
Lakeshore	25.92901	88.2988	103.2489	51.04045	14.48287	283
Lower Shire	35.54932	121.0598	141.5567	69.97771	19.85638	388
Middle Shire Valley	33.62526	114.5076	133.8952	66.19026	18.78168	367
Nkhata Bay and South Karonga	26.2955	89.54684	104.7082	51.76187	14.68758	287
Phirilongwe Hills	14.38465	48.98556	57.27941	28.31572	8.034668	157
Rift Valley	31.24309	106.3954	124.4094	61.50103	17.45109	341
Shire Highlands	45.81098	156.005	182.4185	90.17747	25.58811	500
Thyolo Mulanje Tea Estates	34.08337	116.0677	135.7194	67.09203	19.03756	372
Western Rumphi, Mzimba	33.71688	114.8196	134.26	66.37061	18.83285	368
Total	444	1512	1768	874	248	4846

Table A14 – Chi Square Value

Region	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 4 acres	4 acres or more	Total
Chitipa, North and Central Karonga, Misuku Hills	8.2465	0.0108	5.5361	0.0068	8.1280	21.9283
Kasungu Lilongwe Plain	40.1107	37.3903	4.2039	44.5579	30.9896	157.2525
Lake Chirwa and Phalombe Plain	7.8642	17.8100	2.9645	13.6540	6.9622	49.2549
Lakeshore	2.5123	0.0328	0.0733	1.9751	0.4257	5.0191
Lower Shire	5.0893	45.1607	12.7940	15.5411	7.0795	85.6646
Middle Shire Valley	3.8478	0.6321	0.1258	0.2193	6.1893	11.0143
Nkhata Bay and South Karonga	7.7717	0.1332	3.1954	0.8833	0.0322	12.0159
Phirilongwe Hills	0.9087	2.9326	0.0517	1.5779	0.0001	5.4710
Rift Valley	6.9701	0.0015	0.0160	2.5410	0.0117	9.5402
Shire Highlands	0.5052	0.0575	0.5033	0.0154	1.6962	2.7776
Thyolo Mulanje Tea Estates	35.7703	3.4230	11.0462	4.8787	0.2023	55.3205
Western Rumphi and Mzimba	4.0717	6.7404	0.4462	4.1665	12.2150	27.6398
Total	123.6685	114.3247	40.9565	90.0170	73.9318	442.8986

Appendix B

Figure 1 – Political Map of Malawi

Figure 1 - "Malawi" 2004. United Nations Department of Peacekeeping Operations Cartographic Section. Map No. 3858 Rev. 3

Figure 2 – Map of Malawi Displaying North, Central, and Southern Regions

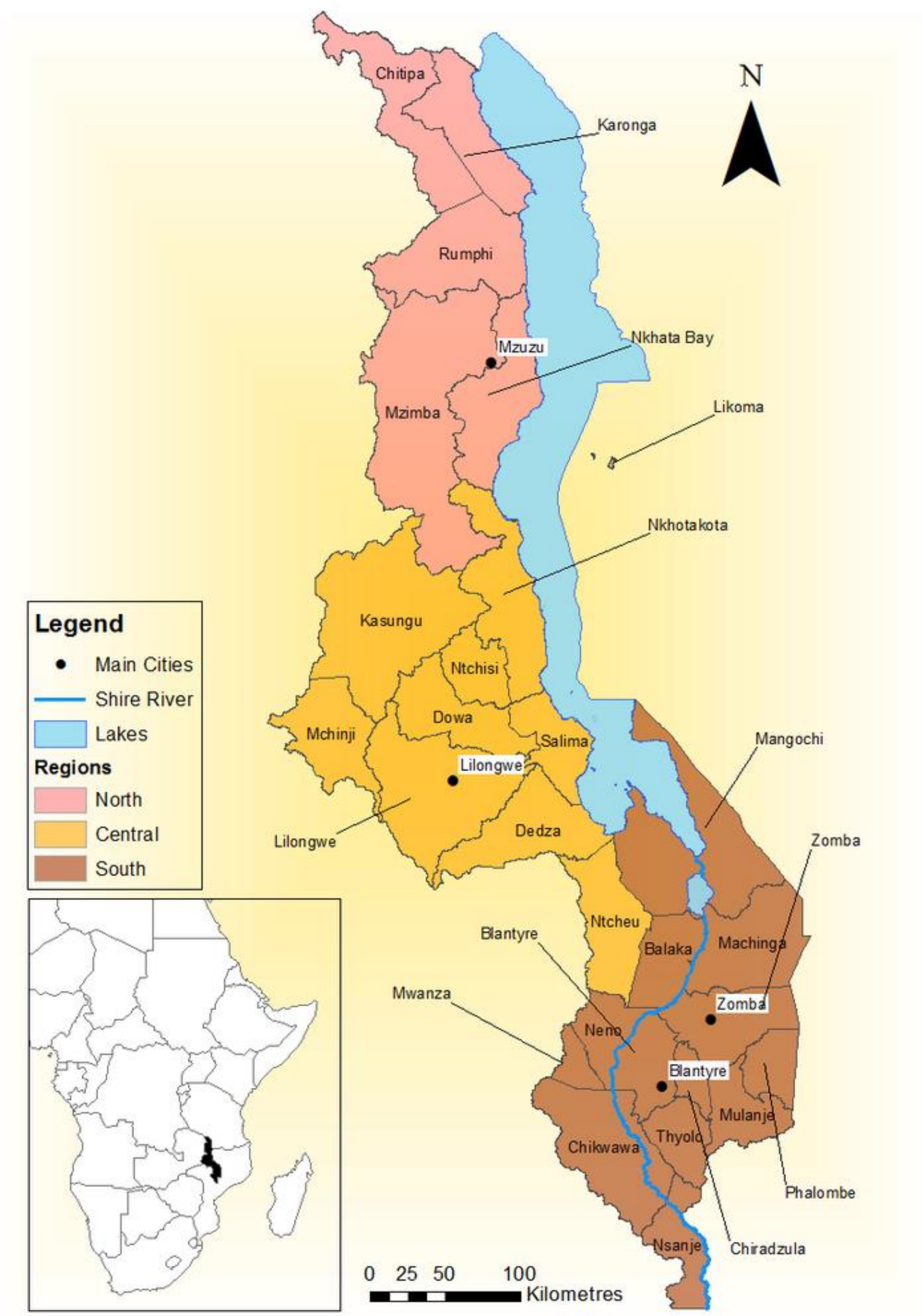

Figure 2 - "Map of Malawi." GIS Research, University of Edinburgh. Deirdre Kelly.

Figure 3 – Map of the Areas (Livelihood Zones) used in the Linear Program Analysis

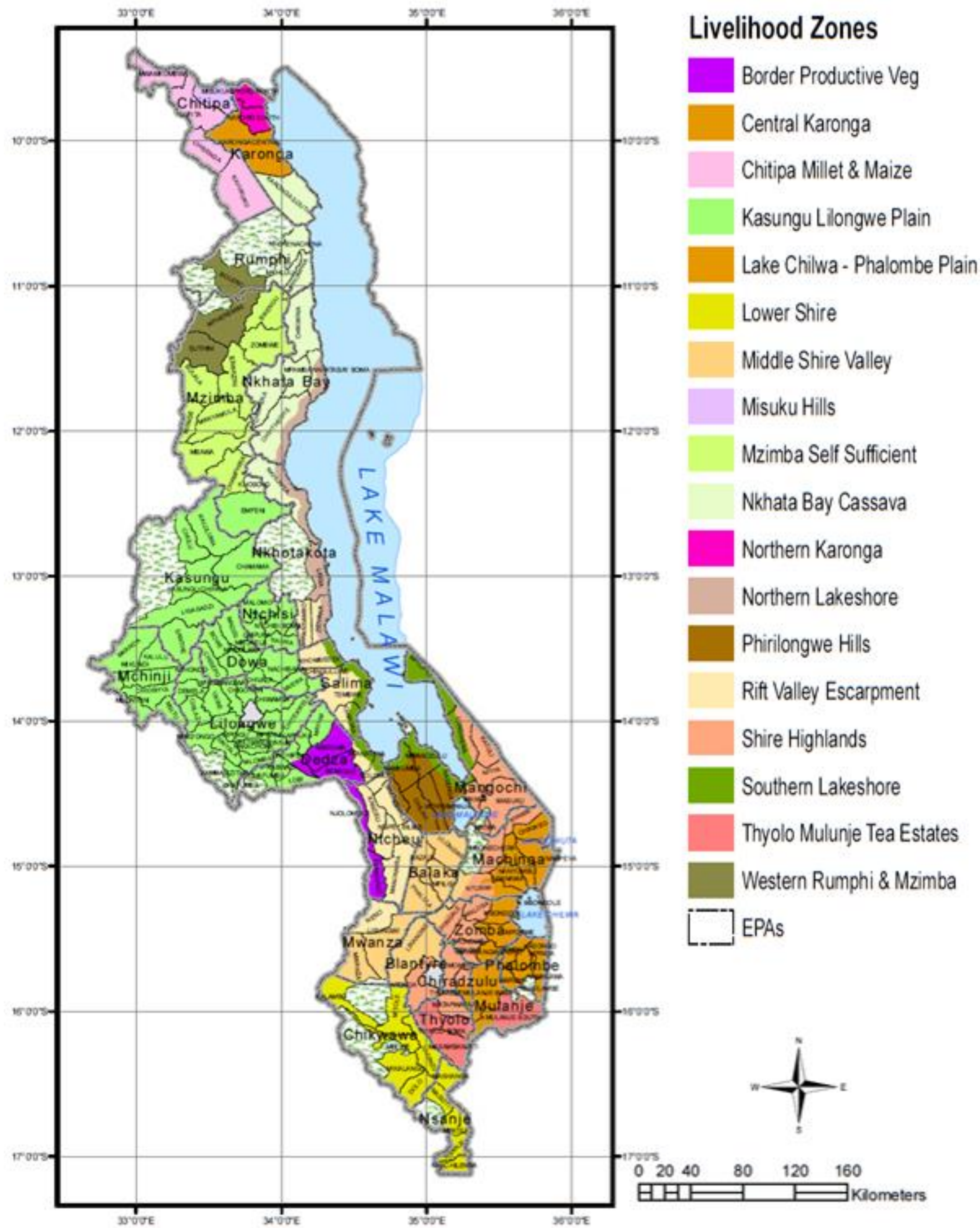

Figure 3 - "Livelihood Zones, EPAs and Districts in Malawi." Malawi VAC Food Security Monitoring Report. 2005.