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Analysis of Building Resiliency in an Ethiopian Pastoral System: Mitigating the Effects of Population and Climate Change on Food Insecurity

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ANALYSIS OF BUILDING RESILIENCY IN AN ETHIOPIAN PASTORAL SYSTEM: MITIGATING THE EFFECTS OF POPULATION AND CLIMATE CHANGE ON FOOD INSECURITY

by

Brigham Forrest

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ABSTRACT

Analysis of Building Resiliency in an Ethiopian Pastoral System: Mitigating the Effects of Population and Climate Change on Food Insecurity

by

Brigham Forrest, Master of Science

Utah State University, 2014

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Worldwide expenditures on international development in the form of assistance or "aid" have continued to increase as developed countries look to both help and influence developing countries. In 2011, more than $140 billion in development aid was distributed globally, more than double the amount expended for international development aid in 2003. Many of the countries that are in need of aid have governments that do not have the resources, the experience, political stability, or well-functioning institutions to effect long-term structural change to bring their people out of poverty.

Ethiopia is a country receiving large amounts of development aid, and one of the poorest regions in Ethiopia is the Borana Plateau in the Oromia state. The people are semi-nomadic pastoralists who live off the livestock they raise.

Climate change, as well as overgrazing and population growth, has reduced the amount of land available for pasture. Additionally, drought conditions can cause huge livestock losses due to death and the pressure to sell animals during droughts to generate money to buy food. The pastoral system is in constant danger of overstocking and suffering a system crash when drought events occur.

Linear programing was used in this study to test various “scenarios” that shed light on how drastically drought and overpopulation impacts livestock numbers and overall livelihoods of the Boran pastoralists. How well livestock survive through droughts determines, in large measure, the need for food aid in the Borana Plateau and, with climate change increasing the frequency of drought events, the system struggles to rebound following droughts. These scenarios examined in this study tested the economic incentive the Boran have to clear land, and what impact clearing land has on livestock numbers, especially during drought years. The analysis also tested how keeping livestock in the system, as a result of drought mitigation strategies such as brush clearing, reduces the need for food aid during droughts and also reduces the rebound time for livestock numbers following a drought.

The results determined that brush clearing provided the forage needed to keep cattle alive through a drought at various stocking levels up to and including estimated full capacity. This suggested that brush-clearing activities created an environment where people could return to pre-drought production levels without any rebound time following a drought if enough brush clearing and/or kalo development is undertaken. Kalo(s) serve as forage reserves, created from land cleared of brush and produce much more grass than from brush clearing alone and do it at a lower household cost. (161 pages)

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Brigham Forrest

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CHAPTER 1

INTRODUCTION

Worldwide expenditures on international development in the form of assistance or "aid" have continued to increase as developed countries look to help and influence developing countries. In 2011, more than $140 billion in development aid was distributed globally; more than double the amount expended for international development aid in 2003 (WB 2014). Of the total amount of development aid, more than $120 billion came from the Development Assistance Committee (DAC) that consists of 26 member countries who pledge to donate a certain portion of their gross national income (GNI) as aid each year. Although their goal of donating 0.7 percent of GNI has not always been achieved since their inception in the 1960s, the DAC has given more than $3 trillion USD in aid and assistance during their existence (Shah 2012). In 2012, there was a renewed effort on the part of the DAC members to continue their existence and to reaffirm their original commitments to donate a percentage of their GNI. A great deal of development aid from both public as well as private sources is actually administered through non-governmental organizations (NGOs) (WB 2012a).

International development aid represents a huge effort and indeed is a large and important industry. Hundreds of thousands of people are employed in these efforts. Consequently, defining and understanding the goals and effectiveness of these efforts provides insights into the state of the industry and the possible future directions one might expect in the area of international development aid.

Broad categories for expenditures in international aid include development aid and humanitarian aid, the later being the smaller in terms of total expenditures.

Development aid is different from humanitarian aid as it is designed to eradicate poverty, build infrastructure, and educate people in the long run while short-term efforts are typically more related to humanitarian relief (globalhumanitarianassistance 2014). The primary focus of NGO's is to deliver aid programs (both development and humanitarian) at the behest of donors in a way that improves the well-being of the recipients. The NGO programs can be delivered on many levels, from the national, to the community down to the individual.

International development aid is needed as much now as ever. The World Bank estimates that more than 1.8 billion people live below the $2 a day poverty line.[1] Sub-Saharan Africa (SSA) is among the poorest places on Earth with 441 million people living below the poverty line (WB 2013a). Many of these people live in countries where governments lack the resources, the experience, political stability, or institutions to effect long-term structural change to bring their people out of poverty (WB 2013a). Poverty alleviation is just one area of focus for development aid, but by far the most highly funded and popular type of aid provided.

The historical effectiveness of decades of foreign aid and NGO interventions are reported as having mixed results. Although there can be immediate and short-term relief from hunger and poverty as a result of these programs, the long-term result in general should be to bring about structural changes to effect long-term improvement in the lives of the aid recipients. The largest weakness in NGO and development aid programs is their lack of research base on the long-term effectiveness and sustainability of interventions (Werker and Ahmed 2008). If an NGO is mainly concerned with donor expectations and not getting bottom-line results for aid recipients, the distribution of the

[1] This level of income ($2/day) is the measure of poverty used by the World Bank (2012b).

aid to the recipients may come in a way that is not useful or sustainable (Erickson 2013; Erickson et al. 2013Werker and Ahmed 2008). Development aid interventions delivered by governments or NGOs may be helpful in short-term relief, but the opportunity cost for recipients to participate in the programs may not be considered. (Erickson 2013; Erickson et al. 2013). As a result, recipients may not continue the target behavior of the developmental aid intervention once funding for the aid ends in which case the intervention is not sustainable.

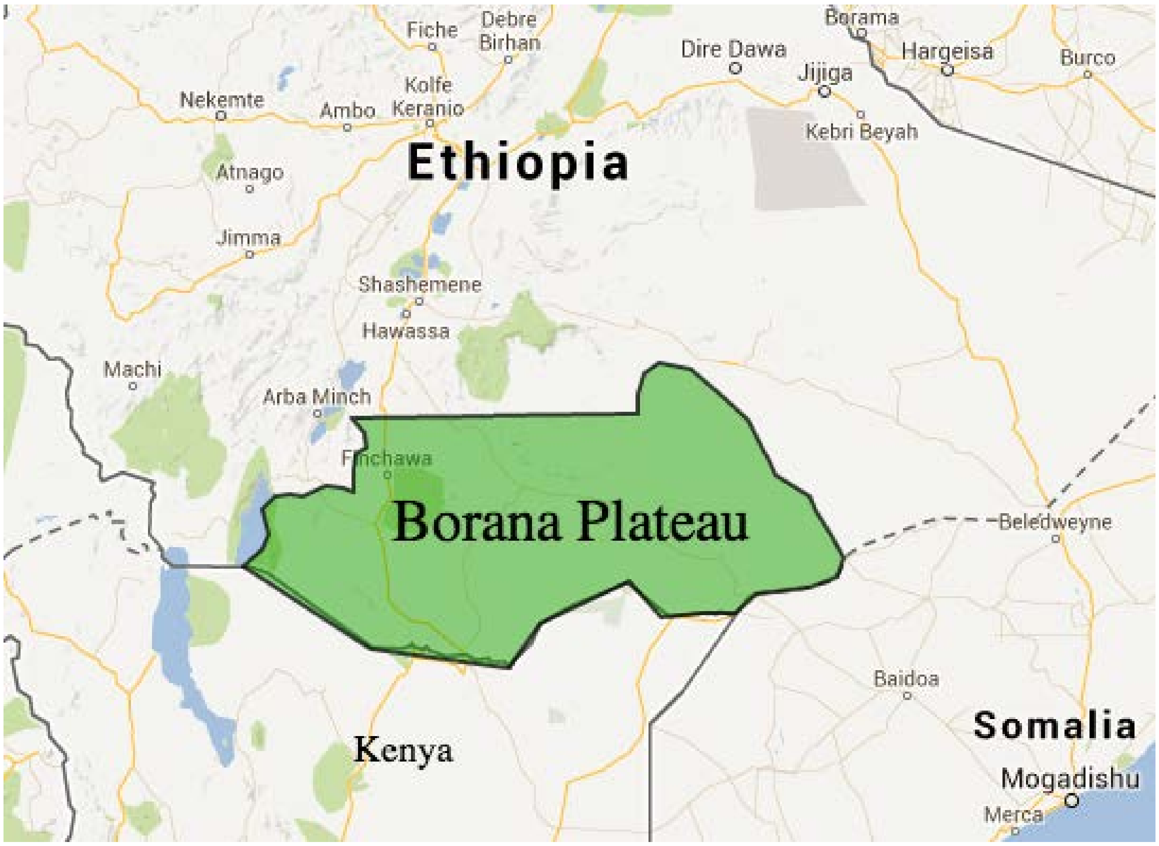
The Horn of Africa is a region of the world that has been a focus of development aid for decades. The wars and political instability endemic to this region have caused it to be an area that has a population in constant need of development assistance. This region is also heavily influenced by climate change as droughts have become more frequent and severe during the past two decades (USGS, 2011). Drought affects many people but the rural populations are particularly hard hit because most rural people are poor and tied to the land (WB 2013a).

Ethiopia is a country that receives some of the largest amounts of development aid of all countries in the world. There was more than $4 billion expended in non-military projects in Ethiopia for 2013 (WB, 2013b). These projects range from infrastructure (roads and facilities) to education, technology, and water sanitation.

One of the poorest, most marginalized regions in Ethiopia is the Borana Plateau in the Oromia region in the southern part of the country (IFAD 2008). The people there are mostly pastoralists who live off the livestock they raise and they are semi-nomadic. The Borana Plateau is a semi-arid[2] region and is known to have little surface water. Pastoralists in the Borana Plateau are dependent on deep wells called tulas with the

[2] Semi-arid is typically defined as areas with between 250 and 500 millimeters of annual precipitations.

remainder of their water being provided by ephemeral and permanent ponds (Coppock 1994). The region is shown in figure 1.



Source: zeemap.com

Figure 1. Map of Southern Ethiopia and the Borana Plateau.

The Boran pastoralists are becoming even more marginalized than before, as they have experienced population growth in their region (Coppock 2014). Because most of the Boran depend on livestock, this has led to overgrazing which has resulted in encroachment on grazing lands by invasive *Acacia* and other woody species. As a result of more frequent and severe droughts, coupled with degradation of grazing lands, many people in the Borana Plateau are attempting to increase food production via opportunistic cereal cultivation. However, efforts to increase cereal production may have unintended negative impacts as rain-fed crops are usually planted in areas favored for dry-season grazing land by livestock (Coppock 1994). These issues are magnified by the impact of climate change. The frequency and impact of drought have increased in the region, reducing the ability to grow crops. Increasing aridity has also had negative impacts on grazing land for the livestock (Coppock 1994). Besides affecting rangeland degradation and cultivation success, climate change and overpopulation is also forcing people to mitigate the effects of resource restriction on land management and changing the livestock species composition to include more browsing camels, goats and sheep relative to fewer grazing cattle (Coppock 2014).

The purpose of this study was to examine the economic sustainability of strategies being implemented to mitigate the effects of overpopulation and climate change on the Borana Plateau. These strategies include a movement to less nomadic herding or a population that is becoming more stationary. The economic viability of brush clearing and the introduction of kalos, preserved grazing areas grown and maintained for dry season grazing, was also investigated. The introduction of kalos is usually accompanied by the implementation of bylaws by the community that uses the kalo(s) during the dry season. This would likely include less tolerance for those not in the community who use community land for grazing, making sure they preserve that area for community needs particularly in times of drought. This essentially provides for quasi property rights to be imposed in some areas as a means to develop, control, and manage additional land for dry season grazing.

Expanding the number of small entrepreneurial businesses amongst the communities of the Borana Plateau could also be an important strategy to people and communities because it may help them to become less reliant on livestock. Such efforts could include micro financing for starting up small businesses as well as capacity building to understand local markets and the ability to find and fill a need in the market. An example of important economic impacts on communities in the Borana Plateau resulting from micro financing efforts is the Pastoralist Risk Management Project (PARIMA). While this study did not directly consider the impact of implementing small entrepreneurial activities in the study area, based on the experience of PARIMA it was assumed that such activities, besides brush clearing and/or kalo development, could help the target communities to deal, at least to some extent, with climate change.

The study of herd diversification and the impacts that it could have on the sustainability of the pastoralist way of life as well as the cultural implications of being traditionally cattlemen was also included in this analysis. The introduction of increasing numbers of browsing camels into the herds in the Borana Plateau has already taken place at a rapid rate in the last few years (Coppock 2014). Camels are more drought resistant than grazing cattle and can be sustained on different vegetation (browse instead of grass). However, the Boran pastoralists are traditionally cattle people and camel husbandry has only been recently integrated into the Boran community.

This study examined the viability of these climate change mitigation strategies. The important aspect of this study for the donor and NGO communities was the potential positive impacts the strategies might have on the people in the region as measured by the estimated viability and sustainability of the actions considered.

CHAPTER 2

REVIEW OF THE LITURATURE

The purpose of this study was to integrate economics, range science and resource management principles into a mathematical-programming framework that could help in decision making by identifying potential interventions that appeared to have the highest probability of yielding the best results to support people. The study was heavily influenced by the role that climate change and population growth was having on the Boran pastoralists as they try to navigate the increasing climate variability in the area with their need for grazing land and ultimately food for the human population.

Ethiopia has, and will continue to receive, a large amount of development aid and humanitarian aid together with many person hours to try and better the welfare of the rural people. It is important to try to have these well-intended efforts maximize their usefulness by considering the complex relationship between economics, range science and pastoral life so that interventions can be sustainable and have long-term benefits to the human population. This chapter reviewed the literature on the impacts of climate variability and underdevelopment on the rural poor, specifically in Africa and the Borana Plateau of Ethiopia.

Climate Change

For the last 15 years, climate change has been one of the issues at the forefront of the scientific community's research efforts. Nearly all the literature agrees that climate change and climate variability have already and will continue to impact global agriculture. The consensus in the literature was that the change in water availability and average temperature resulting from climate change will affect agricultural production and that tropical regions, where some of the poorest countries in the world exist, will be the regions most impacted (Kurukulasuriya and Rosenthal 2003). An increase in average temperatures was identified as only part of the problem arising from climate change. What was more concerning was the changing frequency and variability of temperature and rainfall. The changes that are occurring are not something that can be mitigated by one policy for all locations. Rather, the policies that are going to need to be implemented for impacts on a long- and short-term basis will differ geographically.

Climate is a primary factor in determining the level of agricultural production. Consequently, determining the long-term impacts of climate change on the economics of agriculture and the ability for humans adaptation of agricultural activity in response to climate change, are important to help define policy measures that should be discussed and ultimately implemented. Developed countries, such as the United States and the United Kingdom, may suffer little from the current rise in average temperature as farmers in developed countries have a greater ability to adapt successfully to climate change than farmers in developing countries. This is so because farmers in developed countries are equipped with the technology and the infrastructure to move crop production to areas that will be suitable for good harvests compared to farmers in the developing world.

Many studies for developed countries have resulted in reported positive outlooks for meeting global food production targets as a whole, even with the expected rise in average temperature and change in precipitation that follow climate change (Darwin et al. 2003). However, the ability to meet world demand for food is subject to farmers’ ability to adapt and increase productivity or to increase the amount of land under cultivation.

Additionally, meeting future world food demand is subject to the farmers' ability to maximize production by selecting the most profitable set of inputs and outputs. This leaves developing nations with populations relying heavily on subsistence farming at a distinct disadvantage to developed countries in terms of dealing with the effects of climate change (WB 2013c). It also leaves farmers in regions in the developing world affected significantly by higher average temperatures resulting from climate change with increased costs of production which may have a drastic negative economic impact, not only on the poor farmers, but on the region as a whole (Adams et al. 1998)

Africa is a continent facing an uncertain future in terms of its agriculture as the realities of climate change slowly take effect. This is in part due to the fact that there is a great deal that is unknown, about what makes up the future climate in Africa. The current projection is that with the increase in average temperatures, wheat production in the north of Africa and the maize production in the south of Africa, will be negatively affected by climate change (Conway 2009). With the rise of the sea level over the next 50 years, climate change is certain to have an affect on the Nile Delta (Conway 2009). There are parts of Africa that are projected to see an increase in agricultural production as a result of climate change as they are expected to experience more rainfall but, by and large, there will be a difficult time addressing the problems for agriculture that arise from increased average temperatures in Africa.

The endemic poverty in many of the regions of Africa, particularly in sub Saharan Africa, means many African countries have weak adaptive capacities. With the increase in food insecurity and conflict, more people in African nations are anticipated to move into poverty as a result of climate change (Anthony 2012).

The Horn of Africa is a region that has been heavily impacted by recent droughts (WB 2013c). The people in this region are particularly heavily affected by drought as they already live close to the poverty line and any shock to the agricultural system has a greater impact on their ability to survive than it has in most other places in the world. The people in this region are always in need of additional clean water, food and medicine. However, when a drought occurs the results are often catastrophic. The more variable climate becomes and the more extreme weather becomes, the greater the impacts this region may experience as a result of climate change. This is exacerbated when one considers, as indicated in a recent Oxfam report, that people and policies in the region may be equally to blame for negative outcomes related to agriculture as climate change is itself (Oxfam 2011). Interventions in the Horn of Africa related to climate change should not only be to reduce greenhouse gases and meet humanitarian needs, but to also to build long-term resilience and boost the productivity of smallholder farmers and pastoralists (Oxfam 2011).

The impacts of climate variability have already been seen in the Horn of Africa, as this region is highly vulnerable to weather. Many areas in Africa have such extreme weather variability that there can be a drought and then flooding within months of each other. There are factors, such as poverty, poor access to resources, limited infrastructure, and population growth, which compound the region’s ability to cope with weather shocks.

The increase in weather vulnerability in the Horn of Africa has caused an overexploitation of land resources and deforestation in the region. This has caused increasing risks in the face of drought and flooding in new areas. There will be an increased scarcity of water and a potential increase in conflict surrounding water rights in Africa as nearly all the river basins are trans-boundary (Ashton 2002; De Wit and Stankiewicz 2006). Much of the region uses rainfall to irrigate for agriculture and climate change may cause a loss of agricultural land and shortened growing season with lower yields in parts of Africa (UNFCCC 2007). Africa may have the more people that suffer from hunger as a result of climate variability than any other place on Earth (Fischer et al. 2008).

The effects of climate change were expected to not only effect the agricultural sector in Africa, but also climate-sensitive diseases such as tuberculosis and malaria which are moving into new geographical areas in Africa (UNFCC 2007). As the temperatures gets warmer, previously unexposed regions such as the highlands in Ethiopia could see moderate increases in malaria by 2050 with conditions being highly suitable for malaria possibly by 2080. There was also reason to be concerned, according to reports, that the rise in sea level on the east coast of Africa may also have negative implications for human health (Boko et al. 2007).

The impact of the spread of human diseases as a result of climate change has been looked at but less has been done to examine the impact new geographical regions for livestock disease may have on local economies. However, changes in disease seasonality, prevalence, frequency, and geography will likely happen but it is unknown to what degree. There will, however, be a negative impact on dairy production as the temperature rises (Boko et al. 2007).

Ethiopia

Ethiopia is a country resting in the middle of the Horn of Africa and over the past decade it has seen an economic boom. The capital city, Addis Ababa, is seeing unprecedented growth and investment. However, much of the population of Ethiopia lives in rural areas and relies on smallholder farming and pastoralism as a way of life. The population in Ethiopia is also growing and food insecurity, coupled with rising food prices challenge the stability of this growing nation. Ethiopia ranks 173rd out of 187 countries in the Human Development Index for 2013 (UN HDI 2013). The FAO reports that a 2008 drought led to 4.6 million people in Ethiopia needing food aid. In addition, between 2007 and 2008 the nominal price of maize (corn) in Ethiopia rose by 202 percent (FAO 2014). Ethiopia is dependent on rainfall for freshwater, agriculture and pastoralism, and since the 1960s there has been a steady decline in the average level of annual rainfall across the country (Schreck and Semazzi 2004) resulting in frequent drought and even famine.

The country is highly sensitive to changes in precipitation as rainfall directly impacts the amount of fresh water available (Moges and Gebregiorgis 2013). The majority of agriculture in Ethiopia is dependent on rainfall because there is no wide spread irrigation. When there is a drought in Ethiopia, the impacts on food security in rural areas is devastating; particularly on those engaged in subsistence-level agriculture. There is very little ability for smallholder farmers to adapt to climate change in this situation. Even though they experience the changes in climate and rainfall, they often do not change there farming strategies. This is due to a lack of information, credit, and land (Bryan et al. 2009).

Borana Plateau

The Borana Plateau of southern Ethiopia is a region that is heavily impacted by climate variability. The region is semi-arid with a moderate temperature and is home to a semi-nomadic pastoralist society (Coppock 1994). The traditional pastoralist raises cattle as a source of food primarily from milk offtake, as well as a means of income, from the sale of older bulls. There is also a mix of small ruminants in the livestock herds in the Borana Plateau and camel herding has increased there in the recent past. The traditional pastoralist society is unable to manage the impact of the frequency of droughts as is evident by the loss of livestock, famine risk, and growing poverty that occur during droughts (Coppock 1994).

The Borana Plateau is already stretched to capacity in terms of the number of livestock it can support. Consequently, when there is less than normal rainfall in any given year, the mortality rate of livestock becomes a desperate problem for people in the region. In surveyed research with pastoral households it has been found that over 50 percent of the cattle die in recurrent droughts (Desta and Coppock 2002). The herds of poor pastoralists sustained even greater losses than those of wealthy pastoralists. pastoralists suffered the biggest loss, not in total number of livestock but in terms of a reduction in their ability to restock as well as a loss in their overall wealth. Drought not only causes animals to die, but they decrease the ability of pastoralist to generate income through sales of animals and dramatically reduces caloric intake via reduced milk yields (Coppock 2014).

During the 1983-84 drought, the net impact of the drought on milk offtake for human consumption was a reduction of 92 percent. The severity of the impact of this on pastoralist was the combination of lost milk animals from animals that died and a 65 percent reduction in offtake per lactating cow for the cows that lived (Coppock 1994). The high death loss in the times of drought is not from a lack of water as much as it is from lack of forage (Coppock 1994; Hogg 1997).

The impacts of climate change in the Borana Plateau are further intensified as population increases and available grazing land shrinks due to cropping. The pressures on the system from high stocking rates for cattle in a shrinking geographical area have resulted in overgrazing and bush encroachment (Coppock et al. 2008; Kamara, Swallow, and Kirk 2004). The system is strained even in years with normal rainfall. However, increased climate variability and lack of investment in water storage create a desperate situation for the pastoralist system during droughts. During droughts pastoralist households are forced to sell livestock that do not die at a higher rate than desired in order to buy grain to offset the energy loss resulting from poor milk production. The market price of grain during droughts rises while the market price for cattle declines. As a result, during droughts the net energy derived from an animal (milk and income to purchase grain) is reduced (Coppock 1994).

Some of the communities in the Borana Plateau have tried to fill in the gaps in nutrition during these times by diversifying into cereal cultivation. These are small-scale efforts that typically annex the best grazing land for crops (Kamara, McCarthy, and Kirk 2002). The de facto privatization of cropland to use for cultivation has to be approved by the community (Kerven and Cox 1996), and it shows a change in the attitudes of some of the Boran toward becoming less mobile. The practice of crop cultivation has been seen as a serious threat to livestock production and traditional resource management practices

(Solomon, Snyman, Smit 2007). The cereal plots are completely dependent on rainfall, and even in normal rainfall years there may not be enough to produce a crop (Desta and Coppock 2002; Desta 1999). With increased variability in the climate, there is no way to predict if the amount of rainfall is enough to produce a crop. However, the land is cultivated despite knowing whether or not enough rain falls to yield a crop. Expanding cropland can undermine the use of key grazing areas for livestock (Desta and Coppock 2002).

Food Aid

Hunger is a global issue that has been tackled by many but much more work is needed, according to the World Food Programme (WFP 2013). For example, the World Food Programme estimates that $3.2 billion is needed per year to reach all 66 million hungry school-age children and nearly half of the deaths of children under five on a global basis are a result of poor nutrition (WFP 2013). The United Nations, as well as other governmental and non-governmental organizations, has used donated food aid to help improve the lives of the world's poorest people. The ultimate goal of the WFP's food aid program is the elimination of the need for food aid (WFP 2013). Climate change is a huge impediment to solving global hunger and it threatens any gains made against hunger over the past two decades (WFP 2013).

Ethiopia is a country that has received a large amount of development aid over the past two decades, with a good portion of this aid coming in the form of food aid (WFP 2013). The United States alone contributed $235 million USD in food aid to Ethiopia in 2013 through their Food for Peace (FFP) program (USAID 2014a). (Figure 2).

The drop in milk production in Ethiopia in combination with the death of livestock during a drought coupled with the price increases for cereal grains and a drop in cattle prices (Coppock 1994), result in hunger and eventual famine for many people in the Borana Plateau. The acute food insecurity and resulting malnutrition that currently existed impacted more that 2.7 million Ethiopians in 2013 (USAID 2014b). Many of these people are children with a reported 20 percent of children in Ethiopia under the age of five being severely, chronically malnourished or stunted, causing irreversible physical and cognitive impairments (USAID 2013).

Food for Peace Contributions

Total Contributions:

	U.S. Dollars	Metric Tons
Fiscal Year 2014	$69.8 million	92,230 MT
Fiscal Year 2013	$235.5 million	274,770 MT
Fiscal Year 2012	$306.6 million	365,400 MT
Fiscal Year 2011	$313.3 million	371,599 MT
Fiscal Year 2010	$451.7million	704,200 MT

Source: USAID.gov

Figure 2. Food for Peace Contributions.

The 2011 drought in the Horn of Africa left more than 4.5 million people in need of emergency food relief, and those most severely affected were pastoralists in southern Ethiopia (WFP 2013). It was estimated that from August 2012 to December 2012, emergency food relief totaled more than $189 million USD for Ethiopia (WFP 2013).

The deployment of food aid to isolated rural areas has always been an obstacle in getting relief aid to the poorest people. During the 1983-84 drought, pastoral household surveys reported that everyone in the region, through all wealth classes, felt hunger. It was reported that only two of the forty-four households surveyed received relief grain and that famine relief came in large quantities in late 1985 (Coppock 1994). During this time, Ethiopia relied heavily on aid from the USSR because Ethiopia at that time was ruled by a Marxist regime and the U.S. and others were hesitant to assist a socialist government (Clay and Holcomb 1986).

During the 1984-1985 drought, Ethiopia was involved in a civil war and the government was not sending aid to areas under rebel control. Twenty-five years after the 1984-1985 drought, the political landscape in Ethiopia has changed as they are no longer at war and the government has moved to a more democratic system and has decentralized authority (WB 2013d). The change in politics in Ethiopia has meant that Ethiopia has seen a huge increase in the amount of aid it receives but poor existing infrastructure has inhibited the deployment of relief aid to the most remote rural areas, particularly in the southern part of the country. However, there are key infrastructure projects that will help with aid deployment in the future. The road network is scheduled to increase by 15,000 km by 2015 and there will be construction of 2,395 km of railway line during that same period (WB 2013d).

The problems surrounding the distribution of humanitarian relief aid seem to always hinder progress. However, with some of these issues being addressed in the Borana Plateau the task of building resiliency in systems to reduce dependency on food aid is key. The research in this study focused on the impact of drought in the Borana

Plateau and how it changes the pastoral system. Additionally, this study tested what strategies might be effective in helping pastoralist survive dry years and rebound after droughts with as little need for outside intervention (food aid) as possible.

CHAPTER 3

METHODOLOGY

The government of Ethiopia reported that 2.7 million of its people face acute food insecurity and many of these are in rural populations on smallholder farms. There is a significant amount of money being committed to help the people in Ethiopia survive problems they face because of hunger. Through January 2014, there has been $86.8 million USD in Title II emergency aid, or 92,330 MT pledged to Ethiopia through Food for Peace (USAID 2014b). While there may always be a need for food aid to alleviate short-term hunger problems, this study examined the possible intervention strategies that might reduce medium to long-term dependence on food aid in a particular study area in Ethiopia. The region and people of the study area are some of the poorest in Ethiopia and are located in the Borana Plateau. The Boran people are primarily pastoralists. Decades of overgrazing, coupled with more-frequently occurring severe droughts as a result of climate change, have led these people to look at different ways of coping within their system and with the ultimate goal of meeting people's daily nutritional requirements.

The approach and analysis used in this study was to create an initial, integrated model that could measure the impact of various possible drought-mitigating interventions and how these interventions could be expected to affect the system. The analysis took into consideration the interconnectedness of the economic and agronomic factors in the system and applied economic principles to illustrate the effectiveness of proposed interventions. The intent behind applying economic principles to this problem was to ensure that any interventions proposed and/or adopted would likely be maintained (sustainable) if and when any aid is withdrawn. As a result, sustainability was defined to mean that an intervention would be economically viable to the community and, as a result, the individuals within the community would be incentivized to keep the program operational without continued outside help or aid.

It was recognized that there were relationships between agronomics, financial decisions, and human and livestock nutritional requirements of the community when analyzing possible interventions. A linear programming (LP) model was used to show the relationships between these different aspects of the system and how they would change as a result of different scenarios (interventions). As a result, the LP required a minimum nutritional requirement for the community be met while it was maximizing returns to livestock and cropping activities. The LP was also used as a metric to determine how likely particular interventions were to succeed (be sustainable or adopted by the community in the long term).

Process for Gathering Data

The importance of data collection and having an understanding of the participants in the system were a key to the quality of the results generated by the LP. A basic understanding of these factors was provided by Dr. D. Layne Coppock's seminal book *The Borana Plateau of Southern Ethiopia: Synthesis of pastoral research, development and change, 1980-1991*. This book served as a baseline in understanding the pastoralist system of the Borana Plateau including; livestock sales, labor requirements, household roles and a myriad of other subtleties to the Boran pastoralist way of life. Dr. Coppock also served as a vital consultant for other information and data used in this study.

Field Visit to Ethiopia

A personal visit to Ethiopia was invaluable for me to understand the work that was taking place there to improve the well-being of the people in the Borana region. My visit included meetings in Addis Ababa in May 2013, with NGOs and Oromia[3] government officials and professionals to discuss various drought-mitigating strategies (interventions) currently in implementation or being considered for implementation in the Borana Plateau. As a result, a pulse was taken on the work already being done by NGOs and governmental organizations in the study area and an understanding was achieved regarding the future work plans these groups had for work in the study area.

A field visit to the Borana plateau was made in the same month (May 2013) and, using the southern Ethiopian town of Yabelo as a base, various data-collecting activities were used to paint a picture of the economic rules that would need to be employed in the LP. Drs. Coppock, Ben Norton, and DeeVon Bailey from Utah State University (USU) were part of this field team as were several Ethiopian partners.

Conversations were held with local pastoralists who had gone to university and were working in the region as a part of government research and extension efforts. Other conversations were held with graduate students familiar with the study area. These conversations led to the development of basic information, data, and a basic understanding of what motivates a typical pastoralist's economic decision making. These discussions were helpful to the overall approach for gathering cost and return information on livestock and cropping activities in the study area. The data gathered later helped create a cost benefit analysis for the study area in the form of enterprise budgets.

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[3] The Oromia Regional State is the ethnically-based region within which the Borana Plateau is located.

In addition, the discussions with local professionals and students provided information on the local strategies employed by pastoralists and NGOs working with pastoralists to hedge against risk. For example, the growth of agriculture activities (cropping) in the region and knowing that all of the harvest obtained from crops would be consumed in the community during the year with none sold at market was one coping strategy that was identified. Also the use of “kalos,” a forage reserve created out of cleared brush land and protected by a brush fence, is a common method used by pastoralist communities as a hedge against drought. The seedbed in these over-grazed rangelands is such that when brush and acacia trees are removed, grass will return abundantly in a very short period or time (see Figures 1 and 2).

Figure 1. An Example of Heavy Brush Resulting from Over Grazing in the Borana Plateau.

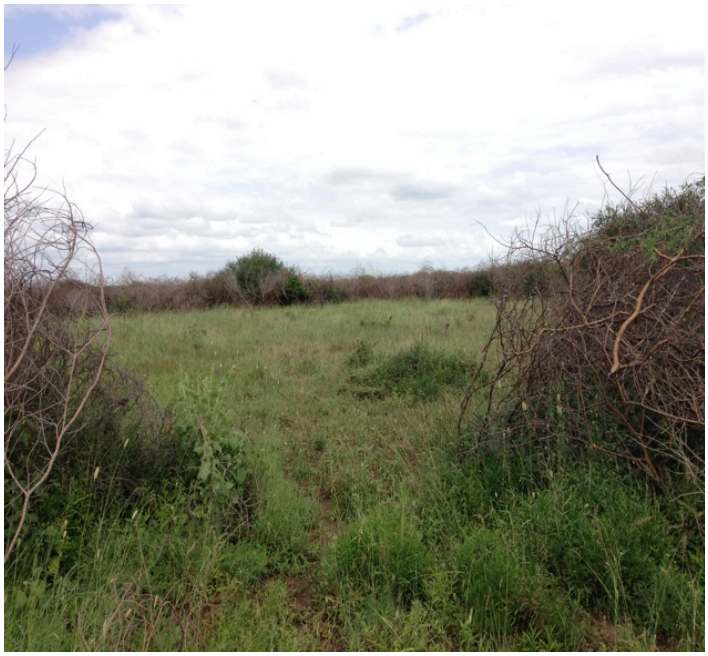


Figure 2. Example of Rapid Return of Grass for Grazing in a Protected Kalo on the Borana Plateau.

A kalo serves as forage storage by preserving valuable grass resources by transferring grass from one season to another. Grass is only produced during the two rainy seasons of the year, but can be "stored" if it is not grazed. Kalo store grass grown in the wet seasons by protecting it from grazing. It can then be used in the critical long dry season when no grass grows and livestock are prone to die during periods of little rainfall. Additional conversations and interviews were conducted during the field visit to the Borana Plateau with professionals working in the study area (Dr. Solomon Desta and Mr. Seyoum Tezera). These visits provided information that supplemented and clarified information gathered from Dr. Coppock's book.

Dr. Desta and Mr. Tezera were able to provide information on the management practices of kalos as well as other drought-hedging strategies; most notably the integration of camels into the livestock herd mix. The presence of camels in the region is not new, but there has definitely been a significant increase in the number of pastoralists who raise camels as a risk-mitigating strategy against drought (Coppock 2014). The reason for this is that camels perform better in dry conditions than do cattle. For example, during dry periods camels have an advantage over cattle because of the type of forage they utilize compared to cattle. Camels eat mostly browse from evergreen trees and shrubs, which is more tolerant to drought than either grass or forbs. Female camels also lactate longer than female cattle, and camel milk can be consumed during the long dry season, which is a critical time of year when cow milk may not be available (Coppock 1994).

Effects of Drought in the Borana Plateau

For centuries cattle have been a mainstay of the people of the Borana Plateau. However, overgrazing leading to brush encroachment (see Figures 3 and 4) and increasing frequency and severity of drought (climate change effects) have made cattle production in the Borana Plateau more difficult and risky than in the past.

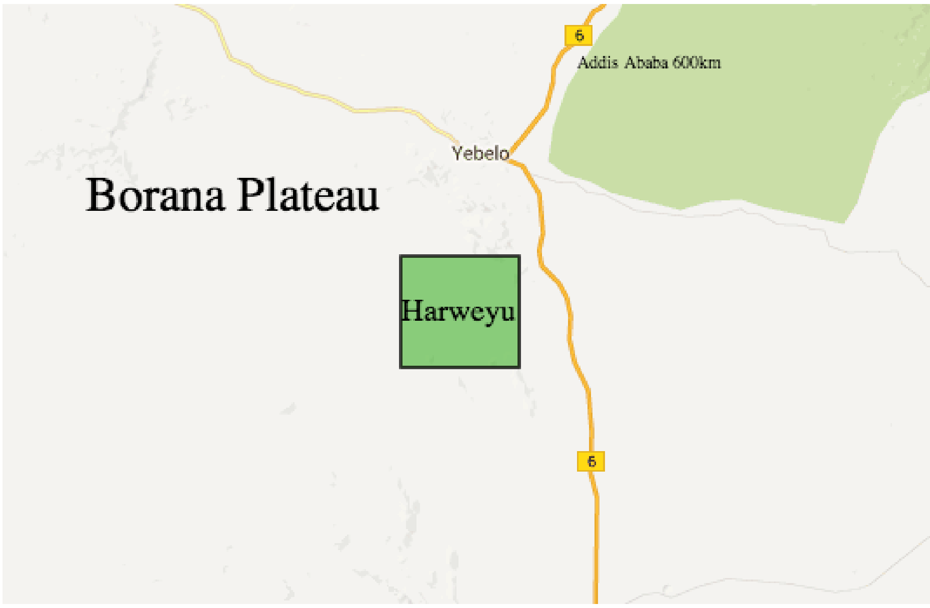
During droughts there is a high death rate for cattle estimated at over 50 percent of the total herd (Desta and Coppock 2002). At the same time, the cows that survive during droughts have a lower percentage of their number that lactate compared to years with normal rainfall. During drought, the milk production of the remaining lactating cows is also greatly reduced (Coppock 1994). As a result, milk production for the community as a whole is greatly reduced during droughts. During droughts the human population suffers because milk is normally a primary dietary staple (Coppock 1994). Cattle also serve as a store of wealth for the Boran pastoralists and when drought occurs and milk becomes scarce, the Boran offload more cattle (those that have not died) at market prices in order to buy grain to meet their nutritional needs (grain, especially maize, has a higher nutritional value per kg than milk). The increased cattle sales at market during droughts drop the price per kg for each animal at the same time grain prices rise. This ultimately reduces the purchasing power of the individuals in the community and places Boran pastoralists in a potentially desperate situation.

Selection of the Study Area

Several potential research sites in the Borana Plateau were considered for study areas including Dikale and Harweyu, both large pastoralist communities severely affected by overgrazing and effects of drought. In Dikale, there were opportunities to meet people who had been positively impacted by previous NGO interventions. For example, one resident of Dikale had been the beneficiary of a USAID project called Pastoral Risk Management (PARIMA 2011). PARIMA was a program that provided opportunities for micro-financed entrepreneurial activities to women in the Borana region. The program enabled employment diversification (away from livestock) and was very successful.

Pond siltation as well as deep gullying were identified as problems in Dikale because they reduce water-storage capabilities and were restricting the movement of livestock. Both of these problems (siltation and deep gullies caused by soil-erosion) have become more severe as a result of climate change (more frequent droughts coupled with overgrazing which has reduced ground cover have led to severe-erosion).

Harweyu was the community ultimately selected as the study area because of its relatively small amount of cropping and high prevalence of bush encroachment. Harweyu is some 40 km south of the town of Yabelo (Figure 5).



Courtesy of zeemaps.com.

Figure 5. Map of the Harweyu Pastoral Association (PA) in the Borana Plateau.

Due to decades of overgrazing the land that the Harweyu community sits on, which was once primarily open grassland (savanna), is now comprised mostly of dense brush and shrubland (Table 1).

Table 1. Rangeland Types Reported Hectares for Harweyu Pastoral Association

Land Type	Cropland	Dense bush Shrubland	Dense Shrubland	Open Shrub Grassland	Dense Woodland	Open Woodland	Riverine Forest	Total
Hectares	100	27,634	25,562	984	247	2,205	32	56,764
% Land Type	0.18 %	48.68 %	45.03 %	1.73 %	0.44 %	3.88 %	0.06 %	100 %

Source: Tezera (2014).

The majority of the land in Harweyu is not as suitable for livestock grazing as it once was, particularly for cattle (Mesele 2006). As such, it was a good choice for the LP model and presented many potential intervention strategies to help the community become sustainable. An interview with the Harweyu development agent provided information on the number of people, households, and livestock are in the community (see Tables 1-3).

Table 2. Human Population of Harweyu

Gender	Number
Males	1508
Female	1559
Total	3067

Source: Harweyu Development Agent (2013)

Table 3. Livestock Population of Harweyu

Livestock Species	Number
Cattle	8700
Goats	6200
Sheep	4200
Camels	900
Chickens	500
Donkeys	240

Source: Harweyu Development Agent (2013)

Household Characteristics

A primary purpose for this study was to determine the food energy produced by the livestock for the human population during both normal and drought years. This allowed for the identifying the existence of daily energy requirment deficiencies during normal and drought years. To do this, it was necessary to develop the characteristics of what made up a typical household (age, gender, number). Through expert opinion (Coppock 2014), a typical household size and family makeup was established. This served as the foundation for the LP analysis in terms of nutritional requirements for the community (Table 4). The typical household spanned a wide range of ages and was comprised of adults and children of both sexes, and daily energy requirments were established for each person, from FAO standards (Coppock 1994).

Table 4. Typical Household and Personal Daily Energy Requirements for a Family in Harweyu

Gender/Age	MJGE Required	Calories
Male 40	10.6	2531.767[a]
Female 35	8.48	2025.413
Female 65	8.48	2025.413
Male 26	10.6	2531.767
Female 17	8.48	2025.413
Male 15	8.48	2025.413
Male 6	6.36	1519.059
Female 2	6.36	1519.059
Total	67.84	16203.304

[a] Daily energy required was converted from MJ (mega-joules) to calories. An average household was used based on FAO guidelines to assess energy demand (Desta and Coppock 2004 refined with expert opinion; AAME = African Adult Male Equivalent; ≥ 16 yrs old, 55 kg, 10.60 MJ GE/d, Coppock 1994 p. 165).

Nutritional Requirements

Information was gathered at the nearest large market (Yabelo) on the type of foods that were available to the people of Harweyu. Prices for these different commodities were collected on a per kg/liter basis (see table 43 in Appendix for items and prices). This information was further refined using expert opinion (Tezera 2014). Nutritional information for these foods was obtained using Genesis, a nutritional labeling software that accesses a database of micronutrient level elements of nutrition for various food types. The nutritional information gathered was supervised and refined through expert opinion provided by Dr. Karin Allen, a PhD dietician in the Department of Food

Sciences and Dietetics at USU. Dr. Allen works in the area of food quality extension at USU (see Appendix for a list of micronutrients from the foods available to Boran pastoralists). For the purposes of the LP, it was decided to focus only on daily energy requirements (calories), as energy is a limiting nutrient in pastoral systems (Coppock 1994). Most of the nutritional requirements were assumed to be met by the consumption of milk and maize. These two foods make up the largest percentage of the pastoralist diet (Coppock 1994).

Medical and Education Costs

Household information was also used to estimate medical and education costs. These cost have a wide variance, even when considering the typical household described in Table 4. The typical family relies on children and youth to participate in livestock-related activities. This impacts how many children a household can send to school. The proximity to schools is another barrier to education in these communities and distance to school raises the costs of education per family. Students enrolled in local schools stay in town for the week and need to pay for lodging and food on top of any uniform and tuition requirements for schooling (Tezera 2014). Medical and school expenses for the family (Table 5) used in the LP were refined through expert opinion (Bailey 2014; Coppock 2014) to capture a realistic cost obligation that a household could expect to have per year for these expenses.

Table 5. Estimated Household Costs for Medical and Education in Ethiopian Birr[a]

Expense Type	Annual Amount Per Household
Education[b]	2,500
Medical[c]	500
Total	3,000

[a.] Exchange rate of $1 USD to 20Birr is used.
[b.] Education is free but there is a cost for room and board in town as well as clothing. This is an average for primary and secondary educations, including the cost of living in town. There is no real estimate for how may children attend school, this assumes half of the children in the household will attend school leaving the other child to work on the homestead (Tezera 2014).
[c.] Medical expenses are an average for the year (Tezera 2014).

Enterprise Budgets

An important consideration in formulating the LP was doing cost benefit analysis. Enterprise budgets provided a listing of all returns and expenses (costs) associated with a particular agricultural enterprise, such as raising cattle or growing maize. Enterprise budgets were used as an aid to prepare cash-flow budgets for an agricultural enterprise. They could also estimate cost and returns associated with the enterprise, provide breakeven prices and yields, and show potential return on investment (Erikson 2013).

The enterprise budgets in this study were used to project the cost and returns for the pastoralist activities among the Boran people in Borana Plateau. Table 6 provided an example of an enterprise budget used in this study.

Table 6. Estimated Costs and Returns for Maize per Hectare in Harweyu Pastoral Association in Ethiopian Birr

	#/Hectare	Life (Yrs.)	Unit	Quantity	Price	Amount Wet Year	Amount Dry Year
Revenue							
Maize[a]			Kg	2,000	4.00	8,000.00	-
Residue[b]			Kg	1,125.0	2.00	2,250.00	-
Total Revenue						10,250.00	-
Operating Expenses							
Seed[c]			Kg	5.4	7.00	37.80	37.80
Tools[d]	#/Hectare	Life (Yrs.)					
Plow[e]	0.375	6	#/yr/ha	0.063	250.00	15.63	15.63
Machete	1.25	4	#/yr/ha	0.313	150.00	46.88	46.88
Hoe	1.25	4	#/yr/ha	0.313	75.00	23.44	23.44
Oxen Feed[f]			Kg	90	2.00	180.00	180.00
Total Non-Labor Operating Expenses						303.74	303.74
Returns to Land, Labor &Management						9,946.26	(303.74)
Returns Per Hour of Labor						18.15	(12.79)
Returns Per Day of Labor						145.20	(102.31)
Labor[g]							
Land Prep[h]			Hours	160	4.75	760.00	760.00
1st plowing[i]			Hours	96	4.75	456.00	456.00
2nd plowing/Sowing[j]			Hours	106	4.75	503.50	503.50
Weeding/Hoeing[k]			Hours	74	4.75	351.50	351.50
Harvest[l]			Hours	112	4.75	532.00	
Total Labor Expense						2,603.00	2,071.00
Returns to Land & Management						7,343.26	(2,374.74)

[a] Cost and Returns calculated assuming ten households plant a total of eight hectares. 75 percent of the area planted is maize (Tezera 2014)

[b] Value of crop residue is calculated at 2 Birr per kg. This is based on bales of crop residue weighing approximately 18.75 kg being sold for 40-60 Birr per bale

[c] Seed is purchased at 7 Birr per kg approximately every third year (year following a drought). Other years some seed is held over and planted (not purchased). Seeding rate is 18kg per hectare (Tezera 2014). Consequently, average purchased seed expense is calculated as 30 percent of 18kg.

[d] Tools are depreciated using straight line depreciation. The cost of tools as well as their lifespan is an average based on if they were purchased in Addis Ababa or locally (Tezera 2014).

[e] Depreciation based on three plows owned among the 10 households jointly farming 8 hectares (Tezera 2014).

[f] Calculated by the cost of feeding 6 oxen for fifteen days at 2 Birr a day per bale.

[g] Total daily hours worked per person is eight with six hours dedicated to field work and two hours dedicated to prep and transit (Dr. Coppock and Dr. Bailey 2014). Costs assumed to have an opportunity cost of 4.75 Birr/hour ($2/day * 19(exchange rate)/8 hours).

[h] Land prep includes brush clearing, taking one week per hectare for new land. In the years after the initial clearing, land preparation takes two to three days (Tezera 2014).

[i] First plowing takes a pair of oxen six days to plow one hectare (Tezera 2014).

[j] Broadcast seeded and then plowed a second time to cover the seed (Tezera 2014).

[k] Weeding and hoeing is done after seed is covered, takes three people four days working six hours a day (Tezera 2014).

[l] It takes seven days for two people to harvest one hectare (Tezera 2014).

A list of the enterprise budgets developed for the three different cereal crops typically planted by the Borana as well the different species of livestock they raise is presented in Table 7. These enterprise budgets were used as the basis for the economic portion of the LP and allowed the model to select those agricultural activities the Boran would choose to pursue if their objective was to maximize profit. There were many assumptions and expert opinions used to create the enterprise budgets for this region because there were virtually no records or economic information collected for these agricultural activities.

Expert opinion was also used to estimate the value of community activities such as herding labor and livestock management. Where assumptions and expert advice were used it is detailed in the footnotes for the specific enterprise budget reported for this study (see Appendix for other enterprise budgets).

There are four sections within the enterprise budgets; the first section indicated expected revenue for the activity (enterprise). The second section reports estimated variable or out-of-pocket costs anticipated for the enterprise. The third section reports estimated costs or value for any unpaid labor and also reports estimated depreciation on any equipment used in the enterprise. The last section of the enterprise budget calculated the expected returns to the agricultural activity after anticipated costs were subtracted from estimated revenue for the enterprise.

Table 7. List of Enterprise Budgets Created for this Study

Livestock	Crops
Cattle at Ecological[a] Carrying Capacity	*Zea* mays (Maize)
Camels at Ecological Carrying Capacity	*Phaselus* faba (Haricot Beans)
Sheep at Ecological Carrying Capacity	*Eragrostis tef* (Teff)
Goats at Ecological Carrying Capacity	

[a.] Where ecological carrying capacity is the number that can be maintained based on natural forage production.

Revenue

The revenue section of the enterprise budget (see Table 6) was the amount of revenue that could be generated by selling the products at market. The Boran pastoralists that are involved in cropping typically consume all that they harvest (Tezera 2014). However, the revenue section indicated what revenue they could receive by selling the crop rather than using it for home consumption. This was done as a way to benchmark activities associated with livestock and crops that could be a part of the pastoral livelihood. It essentially represented the opportunity costs of the enterprise. The enterprise budgets were used as a baseline for the LP model to select which activities the Boran pastoralists would pursue to maximize their income. The enterprise budgets could also be used to select what activities pastoralist could pursue to minimize their losses, and participate in activities that limit their reliance on food aid.

Assumptions Related to Crops and Livestock Enterprises

Maize is a staple crop for Boran pastoralists and their diet is heavily dependent on maize meal mixed with milk (Coppock 1994). There are four seasons in the Borana plateau (Table 8); the long rainy season (LRS), cool dry season (CDS), short rainy season

(SRS) and the long dry season (LDS). There are two planting season in the Borana plateau, the LRS and the SRS. They plant maize once per year during the LRS, which lasts from April to June. The crop is always planted not knowing whether or not there will be sufficient rain to yield a harvest and about 75 percent of available hectares for farming are planted with maize during the LRS. The other 25 percent of the cropland in the LRS is planted with a complimentary crop, usually haricot beans. The crop yield for a normal rainfall year was gathered through personal communication from professionals in the field (Tezera 2014). There is no crop irrigation in Harweyu, or in the Borana Plateau for that matter, so drought brings about a complete crop failure. There is no way to forecast if enough rain will fall to yield a crop, so the labor and planting is done not knowing what yield it will return.

Table 8. Seasons[a] in the Borana Plateau

Season	**LRS**	**CDS**	**SRS**	**LDS**
Beginning	April	June	September	November
Days	61	92	61	151

[a.] Where LRS is long rainy season, CDS is cool dry season, SRS is short rainy season and LDS is long dry season (Coppock 2014)

During the SRS, most of the land is left fallow allowing for cattle and other livestock to eat the herbaceous plants and grass that grow on the land. There is a small amount of planting in the SRS, to the tune of 15 percent of available cropland; usually planted with haricot beans. Crop production is increasing at an estimated 20 percent per year in Harweyu (Tezera 2014) and crops could be a source of revenue in the LP.

However, members of the community in Harweyu consume the entire maize harvest (price to buy maize higher than to sell maize) if one is obtained and the LP solutions indicated that if beans were produced they were sold to purchase maize (Tezera 2014). As a result, the entire harvest applied toward the daily energy demands of the community.

Livestock revenue came from the sale of animals in the LP. For cattle, older males were sold at the average market price per tropical livestock unit (TLU).[4] There was also revenue derived from the sale of milk. The Boran typically do not sell milk, but the opportunity cost was calculated based on the average market price in the region. During years of drought, there is a high death loss for livestock. There is also a drop in the number of lactating animals during droughts compared to years with average rainfall (Coppock 1994). These conditions were also factored into the LP model.

Cattle are the livestock species in the area most impacted by drought in terms of a reduction in lactating animals. However, milk production for all species declines during a drought compared to a normal rainfall year. During drought, the Boran are left to sell more animals in order to buy grain to meet their daily caloric requirements. Livestock serve as a store of wealth for the Boran and livestock sales in normal rainfall years are relatively limited (about 10 percent of herd annually). However, during the dry years the Boran are forced to sell more animals because forage resources are greatly reduced and will not support livestock herds at their “normal” herd size. As a result, during drought years the market is oversupplied with livestock. This causes livestock prices to fall during drought periods thus reducing the revenue that can be generated by the sales of livestock that do not die and ultimately reducing the purchasing power of the pastoralists (Coppock 1994).

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[4] That is, 250 kg live weight per animal (Coppock 1994).

Operating Costs

The summation of fixed costs and variable costs in the enterprise budgets represented the total cost for the different livestock and cropping activities. The fixed costs listed in the enterprise budgets for crops were for the hand tools and plows that were used in cropping. There was no powered or heavy equipment involved in cropping, but the hand tools were depreciated using straight-line depreciation over the average lifespan for each tool (Tezera 2014). There was essentially no equipment needed in herding and milking.

Variable costs were the costs of the inputs needed for each production period. The variable cost for cropping activities in the enterprise budgets includes the seed required to plant crops. The little amount of seed purchased in accounted for in the enterprise budgets. The out-of-pocket costs for livestock activities were the vaccines and supplements that livestock required (Tezera 2014).

Return to Labor and Management

This section of the enterprise budget is a summary of the revenue that is left after paying all operating costs. This summarizes what could be paid to family labor and other family resources that contributed to the livestock or farming activity. This section was important because it “paid” for the labor that was used in each activity, and although the opportunity cost may be very low, opportunity costs must be accounted for because there will always be options people must consider when deciding where and how to spend their time. In this study, opportunity costs were considered to be $2 per person per day, or about 40 Birr; the amount considered the poverty threshold in the developing world (WB 2012b). Consequently, this opportunity cost was factored into the time required for livestock and cropping activities reported in the enterprise budgets. The return to land and management provides information beyond returns after cost because it allows proposed interventions to account for the participants' time as a cost, making the activity compete with other activities the participants could pursue. For example, making charcoal, gathering firewood, or other types of such activities could be performed by pastoralists rather than cropping or herding livestock.

Labor

Labor is often also considered as a variable cost. However in this case, labor was unpaid and not included as an actual variable cost but is included in the enterprise budgets at an estimated opportunity cost. Because labor was not an actual variable or out-of-pocket cost, it is included in section of the enterprise budgets separate from the variable costs. The amount of labor required for the cropping activities was calculated using data collected in the field and refined through expert opinion.[5]

The labor involved in livestock activities was generated from previous work based on a 16-hour workday (Coppock 1994). This was refined with expert opinion and reduced to a 12-hour day for adults to capture the amount of labor required per week, at the household level, for each species of livestock (Bailey, Coppock 2014). This captured the fact that there was only 12 hours of daylight in this part of Ethiopia and also to provide a minimum amount of leisure time to adults. The data was also refined for the labor activities for everyone in the household (see Table 4) by age and gender (Table 9).

[5] For the specifics on how labor was calculated for each activity, see the footnote under the labor section of each enterprise budget.

Table 9. Farm Labor Activities[a] (hours worked) by Age and Gender on the Borana Plateau

Activity	Age and Gender of Household Worker							
	Adult Female	**Adult Male**	**Adult Female**	**Adult Male**	**Male Youth**	**Female Youth**	**Male Child**	**Female Child**
	Age 65	Age 40	Age 35	Age 26	Age 17	Age 15	Age 6	Age 2
Livestock Management	2	41	6	6	6	4	-	-
Herding	-	-	-	56	56	16	-	-
Milking	5	-	8	-	-	8	7	-
Deep-well	-	17	6	17	17	6	-	-
Farming	-	8	8	8	8	8	-	-

a. Represents hours per week (Coppock 2014 Data).

Labor required for livestock production was consistent year round except in the dry season (Table 10). During the dry season it becomes essential to take herds to deep (tula) wells so that animals can be watered (Coppock 1994). This is a community activity and is shared among the different residents of the local community. Therefore, additional labor was required in the LP model during the dry season for taking animals to the wells and manually lifting water from the deep wells to the livestock. As a result, labor requirements during the dry season were calculated from previous studies and refined with expert opinion (Coppock 1994; Coppock, Tezera 2014).

Land and Management

Returns, in this section of the enterprise budget, were to land and management because there was no rental charge for using the land. In other words, there were no direct costs associated with the land itself. Positive returns above total operating costs represented a profitable activity and meant that the activity would likely be self-sustaining.

Table 10. Labor Demand[a] per Head by Livestock Type by Season in Hours

Species	Season[b]			
	LRS	**CDC**	**SRS**	**LDS**
Cattle	7.45	7.45	7.45	10
Camels	7.45	7.45	7.45	10
Equines	7.45	7.45	7.45	10
Goats	2.73	2.73	2.73	3.46

[a] Labor demand was calculated separately for large animals (cattle, camels, equines) and small animals (goats, sheep). Activities include herding, milking, livestock management and deep well operations for the dry season.
Calculated from total number of households in Harweyu (383.25), multiplied by the number of hours spent engaged in livestock activities per week per household (228). This was divided by 7 to get a per day demand per animal. 383.25*228/7 = 12483
Livestock activities for large animals were used at .75 of an hour and .25 of an hour for small animals. This number was then divided by the total number of animals for each animal type (large or small), in order to get labor per animal per day. Labor per animal per day was then multiplied by a factor of 15.2 to put it into half-month periods. (20813*.75)/(16700+1900+500)*15.2 = 12.42 for large animals (20813*.25)/(10200+7200)*15.2 = 4.54
Labor in the dry season used the same calculation only adding 50 hours per week per household, going from 228 to 278.
[b.] Where LRS is long rainy season, CDS is cool dry season, SRS is short rainy season and LDS is long dry season.

In the case of the Boran pastoralist, a positive return to land and management indicated the activity was generating revenue rom livestock and milk sales or crops that exceed out-of-pocket costs plus the opportunity costs of labor. However, if the return to land and management were negative, the activity was not generating enough revenue to cover the costs of the enterprise. It also implied that eliminating the activity and pursuing other more profitable enterprises could actually increase revenue to the pastoralists. For the Boran pastoralists, this was particularly true for cropping. In a drought year there would be no harvest and the labor and cost of land preparation and maintenance would have been spent better in another activity. Of course, in a normal year a harvest would be realized and a return to time spent in cropping activities would have been received. This illustrates the risk pastoralists face in their cropping decisions.

Summary of Enterprise Budgets

The enterprise budgets were used as the basis for the economic portion of the analysis for this study. They were the used to help identify the cost and returns for each activity and to help in identifying the costs and risks associated with each activity. They were used to determine how impactful, in the short- and long-term, potential interventions could be for the pastoralist. This was true because the impact of interventions was “felt” through changing assumptions on crop production, livestock revenue, and prices for food, livestock, and crops assumed to result from different drought conditions and interventions.

Labor Calendar

The cropping activity in the study area was less prevalent than in other communities near Yabelo but the trend all over the entire region was for more cropland to be planted; to the tune of 20 percent per year increase in cropland (Tezera 2014). There were two growing periods each year in the model; the first was during the LRS, the second was during the SRS. A crop calendar was created on a bi-monthly basis to capture the labor activities for each month involved in cropping activities[6] and the labor needed for each task involved. A bi-monthly labor calendar for livestock activities was also created using data from Table 10. Although labor requirements for activities such as herding and milking remain consistent year round (basically the same on a daily basis throughout the year), the dry season required moving the animals to deep (tula) wells for

[6] See footnotes in the enterprise budgets for the specifics on the time it takes to perform each task.

watering. As a result, labor requirements for livestock activities were higher on a daily basis during the LDS than during other times of the year. The labor calendar was essential to identifying and labor constraints that existed during different times of the year. When labor was a constraint, it meant that crop and livestock activities would also be constrained. During periods when labor was constraining, the LP would choose those activities having the highest return associated with the use of the limited amount of labor available at that particular time.

Forage Production and Requirements

Forage production for livestock was a major factor in the success of livestock production on the Borana Plateau. Because hay harvest and storage is non-existent, or at least very limited in this region, livestock were assumed to subsistent solely on natural forage. This meant that if forage was unavailable due to drought for extended periods of time that livestock must either be sold or die. For this study, forage production was expressed in three different species groups; grass, forbs and browse. Grass and forbs are herbaceous. This means plants with non-woody stems (Coppock 2014). While browse consists of leaves and twigs from bushes or brush as well as higher growing vegetation. Forbs in this model were flowering plants other than grass such as weeds or other types of non-grass flowering plants (Coppcok 2014).

The forage endowment (production and carryover) for each type of forage was calculated by season.   The amount of different types of forage required of each livestock species was established for each of the four seasons (LRS, CDS, SRS, and LDS) was estimated from animal liveweights, productivity, and intake requirements (Coppock 2014). Forage is the most limiting factor in livestock production in the Borana Plateau; it is what makes the pastoral system thrive or collapse. There is no feed or very limited amount of feed, shipped into the region during periods of drought. Any production (growth) of forage comes during the LRS and the SRS (Coppock 2014). The residual of forage in the model that was available for the CDS and the LRS needed to come from what was not consumed during the LRS and the SRS. Consequently, the entire grazing system relied on forage growth in the LRS and SRS. As a result, it was expected that the amount of feed that was available during the LDS became a limiting factor on the number of livestock the system could manage each year. During drought years, forage available was greatly reduced in the model for each season of the year compared to normal rainfall years. However, forage available during drought years in the LDS was severely limited and the system could easily collapse, that was to say that carrying capacity during the LDS became much smaller than during a normal rainfall year, and livestock needed to either be moved off the system in great numbers (sold), simply perish, or some combination of both.

Herbaceous Production by Season

The endowment of all herbaceous material (grass plus forbs) was gathered by assuming herbaceous plant production (Coppock 1994) at 19 kg DM/ha/day. This base was then scaled up to gain production estimates for the community by multiplying this figure by the amount of land in Harweyu. Herbaceous production was assumed to be the same for all land types of land in Harweyu excluding the 100 hectares of cropland (Table 1). The number of days in each of the four seasons (Table 8) was then used to calculate the total seasonal endowment for both the LRS and SRS. The production composition of the total herbaceous yield was estimated to be 38 percent grass and 62 percent forbs for all land types regardless of the season. However, when a kalo was established, the production within the kalo shifts to 62 percent grass and 38 percent forbs (Menwyelet 1990 as cited in Coppock 1994). The reason for this was that the establishment of a kalo allowed more grass to grow, when grazing pressure was reduced, and subsequently out-compete the forbs (Coppock 1994). There is an estimated monthly loss in available herbaceous forage of 10 percent of the standing grass and forbs each month due to trampling and weather (Norton 2014). This was factored into the LP. For example, the LDS is five months long. Consequently, 50 percent of the herbaceous forage coming into the LDS from the SRS was considered to be lost because of trampling and weather effects.

Herbaceous production in Harweyu was calculated to have 61 percent occurring in the LRS leaving 39 percent for the rest of the year, and this was assumed to be occurring in the short rains (all information for forage production was gathered and refined using the expert opinion from Coppock (2014) and Norton (2014). The feed requirements for each animal were estimated by season, calculating the daily requirement for each animal species and then multiplying it by the number of days in the season (Table 11).

Grass

The yearly endowment for grass was ultimately what made for a successful cattle production season or not. The diet for cattle was assumed to be comprised mostly of grass with an incidental amount of forbs consumed as cattle graze (Coppock 1994). Similarly, equines (donkeys) eat mostly grass with the incidental consumption of forbs. Sheep and goats compete with cattle and equines for grass as they can consume grass as well as forbs and browse. Sheep and goats could vary their diet somewhat by consuming more browse and forbs than do cattle (Coppock 1994). Grass production changed when the bush was cleared and kalos were established. For dense bush and shrubland, the herbaceous yield response to clearing bush and kalo development went up 100 percent and when the kalo was developed the yield response increases more than 250 percent (Norton 2014). The composition of grass to forbs yield also changed, as stated earlier.

Kalo development was impactful because it tool the grass endowment, a limiting resource, and moved it to the most limiting season, the LDS. The kalo was a forage reserve that could control what animals enter, meaning it could be preserved for cattle only, allowing sheep and goats to take advantage of browse and forbs.

Forbs

The yearly endowment of forbs was calculated in the same way as grass, with all production of forbs occurring during the two rainy seasons. The amount of forbs demanded by livestock was also estimated by species and by season (Table 11). The big consumers of forbs tended to be the small ruminants, namely sheep and goats.

Browse

Browse has some intrinsic difficulties surrounding how to estimate the amount of browse available (Coppock 2014). For example taking browse from a tree and drying it, then weighing it and estimating the amount per tree and how many trees per hectare there are was not feasible for this study. The method used in determining the amount of browse was consistent with other forage production estimates used in this study, by using expert opinion (Coppock, Norton 2014). That was, an estimate of the amount of browse needed to sustain the livestock that consume it (camels and small ruminants) was made on an individual animal basis and then scaled up using that number and multiplying it by the estimated carrying capacity for each livestock species (Coppock 2014). Browse demand was also calculated based on individual demand for each animal species by season (Table 11).

Table 11. Forage Demand By Livestock Type per Season (Entire Herd)

Livestock Species	Forage Type and Season			
		Grass/kg		
	LRS	CDS	SRS	LDS
Cattle	379.16	474.0	184.91	582.69
Camels	3.68	5.78	3.15	0.89
Equines	366.00	550.00	366.00	916.00
Goats	3.03	3.72	3.13	37.94
Sheep	12.63	9.30	13.05	44.44
		Forbes/kg		
	LRS	CDS	SRS	LDS
Cattle	20.00	24.97	18.68	6.17
Camels	3.68	5.79	3.16	7.89
Equines	20.00	30.00	20.00	50.00
Goats	3.72	3.24	3.82	2.16
Sheep	6.53	16.11	6.67	5.69
		Browse/kg		
	LRS	CDS	SRS	LDS
Cattle	0.00	0.00	0.00	6.17
Camels	363.16	555.26	374.74	735.26
Equines	0.00	0.00	0.00	0.00
Goats	23.92	39.19	24.80	30.19
Sheep	16.67	30.88	12.08	20.42

[a] The forage demand for each species of animal and what type of forage they require per season was calculated using demand numbers provided by Dr. Coppock and Dr. Norton. The numbers were converted from metric ton to kilograms and divided into 3 categories; grasses, forbs and browse.

The other issue browse raised was that goats and sheep will eat browse as well as camels (Coppock 2014). Browse makes up the primary diet for camels, but sheep and goats cannot reach as much browse as camels. This meant that sheep and goats competed with camels for some, but not all of the browse resource. In the LP, it was assumed that only camels could consume 50 percent of the available browse and the remaining 50 percent camels competed for with goats and sheep. These issues will also be addressed in the section involving the formulation of the LP and the descriptions of the different scenarios (weather conditions and interventions) analyzed in this study. In a dry year, the production of browse did not decline at the rate grass and forbs did. This suggested that during periods of drought, sheep, goats, and camels would fare better than cattle because browse production would not be as adversely affected by drought, as was grass and forb production (Coppock 2014).

Brush Clearing and Kalo Development

Brush clearing and the development of kalos result in a huge boost to grass production and the seasonal availability of forage in the areas where they occur (Figures 1 and 2). The advantage of brush clearing and kalos, in terms of additional grass production is clear. However, the question arose as to what the costs of brush clearing and kalo establishment were and if the additional grass production they produced could pay for the costs of these improvements. The cost for land clearing and also kalo development were calculated to see how beneficial they were from an economic perspective. Data on the number of hours and people needed to clear a hectare of dense brush by hand was calculated from interviews with pastoralists and then refined by expert opinion (Tezera 2014). The daily labor rate (40 Birr per day per person) and cost of tools, including depreciation, were used to calculate the cost of clearing a hectare of land using hand tools. There was an estimated 20 percent increase in the cost for brush clearing when a kalo was added (Bailey, Ward 2014). This was done because there is a brush fence made to protect a kalo and it was estimated that an additional 20 percent labor requirement would be used to move brush to erect this fence. The costs of brush clearing and kalo development were then estimated with the use of chainsaws. Bob

Sturtevant, a retired forester at Colorado State Forest Service estimated the time and costs associated with clearing land and kalo development with a chainsaw (Sturtevant 2014) (see Appendix for land clearing cost estimates). Although costs for both clearing methods were calculated, only the cost for hand clearing (current method) was used in the LP. This was done to show the benefits, if any, of brush clearing and kalo development on the livestock rather than simply just the costs of the intervention itself.

Forage Summary

Forage was the key limiting factor in whether or not the Boran system was able to survive in the LP scenarios without outside intervention (food aid) during severe droughts. As already discussed, the decades of overgrazing and high stocking rates have created an environment where forage is limited in a normal (wet) year. When dry years occur and forage production declines, the bottleneck in the system moves from not only the LDS, but to all seasons. The Boran pastoralists have taken measures to mitigate this by clearing brush and developing kalos. They have also diversified their livestock compliment to include more camels because camels do not compete for grass with cattle, but rather choose browse. Female camels also have a longer lactation period than cows allowing for an extended supply of milk for pastoralists (Coppock 1994). Having camels in the LP model allowed the pastoralists to hedge against dry years, as browse production does not decline like grass does during droughts. The amount of forage available and forage demand per animal were integral pieces to the LP because the forage endowment and its relation to livestock activity connected directly to the ability of the system in the Borana Plateau to feed the human population that resides there.

Parameters Used in the LP

Forage Endowment

The forage endowment (supply) parameters for the LP were separated into the three types of forage available; grass endowment, forbs endowment and browse endowment. These endowments were determined for each of the four seasons, i.e., LRS, CDS, SRS, and LDS. Storage was then allowed for any forage not used during these seasons, but a loss function was imposed on forage to account for loss due to trampling, erosion, etc.

There was another parameter built into the LP for the different forage requirements (demand) for each livestock species (Table 11). Cattle and equines diets center on grass, while camels eat browse. Goats and sheep will eat grass, forbs, and browse. During the initial run of the LP, the model allowed the small ruminants to utilize the full amount of browse available; limiting what was available to camels. This presented a problem as it allowed goats and sheep to consume browse that they could not reach at the tops of the bushes and in trees. By limiting goats and sheep to compete with camels for only 50 percent of the available browse, a more realistic situation was used to describe the system.

The forage endowment under the different scenarios was changed using expert opinion about how forage production would change between normal and dry years and also if brush was cleared and/or kalos developed. The grass endowment increased when land was cleared, adding 1001 kg/ha of dry matter (DM) in the LRS and 648 kg/ha DM in the SRS to the original endowment. The forb endowment also increased adding 614 kg/ha of DM in the LRS and 397 kg/ha in the SRS. The browse endowment decreased by

10 percent of normal production for all seasons because clearing land produced more grass and eliminated browse. Kalo development transferred forage from the LRS and SRS to the LDS, basically acting as a forage reserve. Additionally, kalo(s) were limited to the land that has been cleared of brush. Adding a kalo transferred 1,615 kg/ha DM away from LRS providing 2,002.6 kg/ha DM to the LDS. The change in forbs was 1,615 kg/ha DM from LRS and adding 1,227.4 kg/ha DM in the LDS. These figures were fixed in the LP for the scenarios involved.

Nutrition

Nutrition is a critical component of the LP model because profit can only be achieved after meeting the daily energy demands of the households in the system. That was, a positive return to the economic activities in the system meant that the nutritional needs of the community were more than met (exceeded) by food production by the community and food purchased by the community with income generated by their agricultural activities. In other words, the community was self-sufficient and also generated a surplus. The energy demand for the community measured in calories required could be meet through either consuming milk or grain and was taken from Coppock (1994). Forcing the model to meet the energy demands of the households in the community was done to demonstrate when the Boran needed to purchase food and how much was needed annually. If additional food was needed and income was not available (negative objective function) the difference was assumed to be made up through food aid. This provided insight into how much food aid was needed and the vulnerability of the system especially during periods of drought. During scenarios that involved a dry year, the minimum calories required was reduced by 10 percent per person assuming that people will, unfortunately, eat less than they normally would. The reason for this is that the price for purchasing maize was double in a dry year compared to a normal rainfall year and the price of milk also was assumed to rise from 18 to 20 Birr per liter in a dry year compared to a normal year.

Livestock

The milk offtake from all livestock was forced to have the same nutritional content as well as being sold at the same sale price. This was done because milk from different livestock species is often poured into the same container and mixed together before it is sold (Coppock 1994). The model allowed for milk to be sold after the minimum nutritional requirements for children in the community below the age of six were met in which case excess milk could be sold and generated income for the households in the community. Milk production in dry year scenarios was reduced by 25 percent for all livestock species other than cattle. For cattle, the number of lactating animals was reduced from 28 percent of the herd to 15 percent of the herd with a reduction in offtake of 50 percent (Coppock 2014). This simulates what happens to production as animals compete for forage to just survive.

Livestock sales (revenue) were taken from the enterprise budgets (see tables 36-41 in the Appendix) and represented a percentage of the herd sold at an average price. During dry-year scenarios, the percentage of the herd sold increased while the market price went down. These percentages were fixed over all the various scenarios and data about the percentages sold and price was refined through expert opinion (Tezera 2014)

Labor

The labor demands for livestock and cropping from the enterprise budgets were used in conjunction with the labor calendar to establish the maximum amounts of labor (supply) that the community had available during different times of the year (half-month periods) to contribute to agricultural activities. The LP established labor constraints by half-month periods. That was, labor during each half-month could be used (demanded) for the various livestock activities up to the maximum available for that period. Labor demand which was determined by the livestock and crop activities occurring at each point in the year (crop calendar) based on the labor needs specified by the enterprise budgets, the number of hectares cropped, and the number of livestock in the system. If excess labor were available during any of these half-month periods (labor supply exceeded labor demand after livestock and cropping activities were covered), the model then assumed that this excess labor could be used to clear brush and develop kalos for the scenarios that considered brush clearing and/or kalo development activities (assuming that appropriate economic incentives existed to undertake these brush clearing activities).

Pantry Items

Because households require certain items in food preparation, these items were required to be purchased by households in the community. This constituted a set amount of "pantry" items consisting of: oil, coffee, sugar, spice and salt being purchased (Table 12). The pantry items were not intended to provide nutritional sustenance, but rather capture a minimum expenditure by the households on goods other than milk and maize but were still required for the standard diets of community members. These items were fixed in the model for all scenarios

Table 12. Pantry Items Assumed Purchased Each Month in All Scenarios Given in Amount Purchased Per Household in Ethiopian Birr

Pantry Item	Amount in kg.	Price/kg.
Oil	1	15
Coffee	1	60
Sugar	1	20
Salt	0.0417	0.29
Spice	0.16	2.4

Creation of the LP

Linear Programming Model

LP was used as the analytical basis for this study. Although analyses using LP are comparatively simple, LP can provide powerful insights about the economic and other forces at work in a system. LP also can incorporate and integrate multiple facets of the decisions facing pastoralists including not only economic factors but nutritional, sociological, financial, and agronomic considerations as well. LP is mathematical programming using constrained optimization. This means that an objective function is maximized (or minimized), in this case for an entire pastoralist community (Harweyu) subject to resource constraints that are faced by the community. The LP used in this analysis is described as follows:

(1) Maximize $-\sum_i \sum_j A_i X1_{ij} + \sum_j \sum_k X2_{jk}(B_k Y_k - C_k) + \sum_n X3_n(D_n - E_n) + \sum_j \sum_n F_n (X4_{jn} - X5_{jn}) - \sum_p \sum_q G_q X6_{pq} - HHEXP - \sum_j PANTRY_j$

Subject to:

(2) $\sum_j \sum_k Y_k X2_{jk} = X7_{kj} \ \forall j$

(3) $\sum_i I_i J_i X1_{ij} + \sum_k I_k J_k X7_{kj} + \sum_n (I_{jn} X5_{jn}) \geq CALORIES_j \quad \forall j$

(4) $\sum_j \sum_n X5_{jn} \geq UNDER6_j \ \forall j$

(5) $\sum_k X2_k = 100$

(6) $\sum_j X2_3 = 0$

(7) $\sum_n X3_n \leq CAPACITY_n \ \forall n$

(8) $\sum_j \sum_n \sum_s K_{jns} X3_{jn} \leq FORAGE_{js} \ \forall j \ and \ s$

(9) $\sum_j \sum_{n=4} \sum_{s=3} K_{jns} X3_{jn} \leq \sum_j \sum_{s=3} FORAGE_{js} \ \forall j$

(10) $\sum_j \sum_{n=2}^{3} \sum_{s=3} K_{jns} X3_{jn} \leq \sum_j \sum_{s=3} 0.50 FORAGE_{js} \ \forall j$

(11) $\sum_j \sum_{n=2} X3_{jn} = \sum_j \sum_{n=3} 0.71 X3_{jn}$

(12) $\sum_p \sum_q X6_{pq} \leq \sum_q LAND_q - \sum_k X2_k \ \forall q$

(13) $\sum_k \sum_n \sum_p \sum_q L_{knpq} (X2_{kq} + X3_{nq} + X6_{pq}) \leq LABOR_q \ \forall q$

(14) $\sum_{n=5} X3_n = 250$

where:

$X1_{ij}$ = the i^{th} food purchased during the j^{th} month

$X2_{jk}$ = the total number of hectares of the k^{th} crop planted in the j^{th} month (k = 1 (maize), k = 2 (haricot beans), k = 3 (tef))

$X3_{n}$ = then number of the n^{th} livestock type (n = 1 (cattle), n = 2 (sheep), n = 3 (goats), n = 4 (camels), n = 5 (donkeys (equine))

$X4_{jn}$ = the number of liters of milk from the n^{th} livestock type produced during the j^{th} month

$X5_{jn}$ = the number of liters of milk from the n^{th} livestock type consumed by households in the study community in the j^{th} month

$X6_{pq}$ = the number of hectares of the n^{th} brush clearing activity undertaken during the q^{th} half-month period

$X7_{jk}$ = Amount of food produced in the j^{th} month by the k^{th} crop

$CALORIES_{j}$ = the minimum calorie requirement for the study community during the j^{th} month

HHEXP = total annual household expenses for the community (medical, school, clothing, etc.)

$PANTRY_{j}$ = required expense for pantry food items (salt, pepper, cooking oil, coffee) in the j^{th} month

$LAND_{q}$ = land available for clearing activities in the q^{th} half month period

$UNDER6_{j}$ = minimum amount required for the community for children under the age of six during the j^{th} month

A_{i} = the per unit price paid for i^{th} purchased food

B_k = the per unit price for the k^{th} crop

C_k = the variable costs of production for the k^{th} crop (includes a charge for family labor)

D_n = the average sales revenue per head of the n^{th} livestock type

E_n = the variable costs per head for the n^{th} livestock type.

G_p = the per hectare cost for the p^{th} land clearing activity (p = 1 (brush clearing), p = 2 (kalo development)

I_i, I_k, I_n = the amount of calories in one kilogram of the i^{th}, k^{th}, and n^{th} food products, respectively

J_i, J_k, J_n= the cooked yield in percentage for the i^{th}, k^{th}, or n^{th} purchased or grown food product

(i= purchased food, k=food grown from own crops, n=livestock food product by the community), respectively

L_{knpq} = Labor requirement for the k^{th} crop, n^{th} livestock type, and p^{th} land clearing activity in the q^{th} half month of the year

Y_{jk} = expected yield of the k^{th} crop in the j^{th} month

i = each different purchased food source

j = January, February, March, April, May, June, July, August, September, October, November, December

q = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24

Explanation of Constraints for LP

Equation (2) indicates, in conjunction with equation (3), that the sum of the amounts of all food grown by the community for the year is consumed by the community.

This means that any crops that succeed in growing are consumed by the pastoralists rather than being sold. Equation (3) indicates that the calories from purchased and raised food together with calories from milk consumptions must equal or exceed a minimum requirement for the community during each month. Equation (4) requires an amount of milk be either provided by the community's own animal or purchased to meet the minimum requirements (calcium and protein) for all of the children under the age of six living in the community. Equation (5) set cropping land equal to 100 hectares (the current amount of land dedicated to cropping in Harweyu while equation (6) requires that no teff be grown. The reason for this constraint is that if any teff is grown by the community, and it seldom is, it will be sold rather than consumed. Equation (6) simply requires, at least for this analysis, that teff not be grown which is in line with current conditions in Harweyu.

Equation (7) set limits on the number of each type of livestock that could be produced by the community. These bounds are described in the discussion about the scenarios as being either full capacity or the level of current livestock numbers. Equation (8) requires that the sum of the forage types available each month and consumed by the five different types of livestock may not exceed the available forage for each forage type (grass, forbs, and browse).

Because camels are able to reach some browse that small ruminants are not (such as trees), but still have access to browse that is at levels closer to the ground, the model is restricted as described in equation (9) to allow camels to consume no more than 75 percent of the available browse in any given month. In a similar fashion, equation (10) restricts that no more than 50 percent of available browse in each month be consumed by sheep and goats. Because sheep are kept by pastoralists for cultural reasons and also as a hedge against diseases that is more likely to affect goats than sheep, equation (11) sets the proportion of sheep equal to that currently observed in Harweyu (71 percent).

Equation (12) restricts land clearing activities to be less than the amount of land in Harweyu minus and land used for crops. Equation (13) provides the communities labor constraints during each one-half month period of the year. Finally, the number of donkeys (equine) in the community is restricted by equation (14) to be equal to their current level of 250. Equines are used primarily for portage rather than to generate income or other products in and of themselves (Coppock 2014). Consequently, the model sets this number because otherwise no equine would be selected by the LP because there is no direct income associated with them.

LP Model Scenarios

The benefit of LP programming was that it allowed for testing the effects of the various variables on the overall well-being of the community by changing the values (assumptions) represented in the constraints of the model. This LP was used to see what, if any, benefits various interventions would have on the community based on the assumption that actions that improved the community's income essentially improved the well-being of the Boran pastoralists. For example, "scenarios" were developed to determine the impact that specified changes to forage production during drought years compared to normal rainfall years had on livestock numbers and community income. Other scenarios were developed to determine the potential effects of brush clearing and/or kalo development on the same variables (i.e., livestock numbers and community income.

As previously discussed, climate change impacts this region and scenarios which simulated drought years hopefully provided insights into the stability of the pastoralist system during droughts and what interventions, if any, could help mitigate the impacts of drought in the study area. The scenarios were an attempt to mimic real-life variability in the pastorals system and included potential interventions that might improve the lives of the people in the region. In this case, improved lives were defined as reducing the reliance of the community on food aid while meeting the daily energy demands of the community. This typically required the community to take action to preserve livestock numbers during drought and, in general, to either enhance or improve community income. The scenarios were compared to each other to determine how interventions and climate impacts interacted with the households' economic goals (assumed to be maximizing income). This hopefully provided a broad view of the economic stability of the region and identified potential interventions that would make a real difference in the lives of Boran pastoralists.

All scenarios assumed the households either raised or purchased food at the lowest possible cost while still meeting the community's nutritional (energy/caloric) requirements. Yearly expenses for medical, school, and other requirements (such as for clothing) were set at 4,000 Birr (approximately $40 USD) per year per household for each of the scenarios. A monthly pantry item expense of 97.69 Birr was also established for each scenario. For the two- and six-year olds in the households, a minimum of 75 percent of their energy requirements was required to come from milk and this requirement could be met by milk produced in the household or milk purchased. Because the price for selling milk is lower than the cost of purchasing milk, the model would first try to produce the milk required before purchasing milk.

A description of each scenario used in the analysis presented in this study is provided in some of the following sections. Each scenario was developed using the best available data and expert opinion to mimic actual economic, household, and community conditions in the study area. These conditions were based on 1) estimated forage production, 2) livestock numbers and species, 3) crop production and costs, 4) labor supply and demand, 5) human and animal nutritional requirements, and 6) changes in some or all of these variables based on rainfall conditions in the study area (normal or drought year). All monetary figures were represented in Ethiopian Birr with an exchange rate of 19.41 Birr to $1.00 USD (XE.com 2014) then rounded to 20.00 Birr to every $1.00 USD for simplicity. Table 13 provided a synopsis of the components of each scenario considered in this study.

Scenario 1

The base scenario, referred to as Scenario 1 (S1) for the LP, was developed to fulfill the nutritional requirements for the households while allowing for the sale of any excess milk and crops. This scenario allowed for Harweyu to be fully stocked with livestock without consideration for past losses due to drought (Table 14). This meant that the rangelands are stocked to the “capacity” indicated by the local community as the highest number of livestock that could be carried after a succession of normal rainfall years given current grazing resources. In periods of drought, livestock typically die and it may take several years after a drought to return to livestock numbers that are close to this capacity. A drought during 2011 resulted in many livestock dying in the Borana Plateau, including in Harweyu. Current livestock numbers in Harweyu were only about half of what they would be if herds were at full capacity. However, for this particular scenario it was assumed that livestock numbers had reached full capacity.

This scenario assumed a normal rainfall[7] year when rainfall allowed crops to be grown and harvested and forage conditions, given current forage resources, were at their best (Tables 15-17). This meant that there was no reduction in forage as a result of drought conditions. This scenario allowed the LP model to choose the herd composition based on the utilization of forage and what was most profitable up to the limit of the full livestock capacity (Table 14). The different types of food that can be consumed by members of the community were assumed to be maize, beans and milk. The objective function calculated for this scenario showed how profitable the system was when livestock were fully stocked and there was normal rainfall. It also showed how much food aid was needed. If the objective function was negative it indicated the community would need to purchase food and that income was not available to do so. Table 14 provided a synopsis of the components of S1 and all of the other scenarios considered.

[7] Average rainfall is 700 mm in a “normal” year in the study area (Coppock 1994).

Table 13. Synopsis of the Components Comprising the Scenarios Used to Complete the Analysis

Scenario Number	Level of Rainfall[a]	Stocking Rate	Manual Labor to Clear Brush	Manual Labor to Develop Kalo	Cleared Land Endowment	Kalo Endowment
S1	Average	High	No	No	No	No
S2	Average	Low	No	No	No	No
S3	Low	High	No	No	No	No
S4	Low	Low	No	No	No	No
S5	Average	High	Yes	No	No	No
S6	Average	Low	Yes	No	No	No
S7	Average	High	Yes	Yes	No	No
S8	Average	Low	Yes	Yes	No	No
S9	Low	High	Yes	No	Yes	No
S10	Low	Low	Yes	No	Yes	No
S11	Low	High	Yes	Yes	Yes	Yes
S12	Low	Low	Yes	Yes	Yes	Yes

[a] Level of Rainfall indicated whether the scenario was for a "normal" (average) year or a drought (low) year. Stocking Rate indicated if the scenario assumed an upper bound on livestock numbers equaling full capacity or at current levels (see Table 14). Manual Labor to Clear Brush indicated if excess labor in the scenario could be used to clear brush. Manual Labor to Develop Kalo indicated if excess labor in the scenario could be used to develop kalos. Cleared Land Endowment indicated if the scenario assumed that land had been cleared in previous years (sunk cost) and that only maintenance costs and labor were required to maintain the already-cleared land. Kalo Endowment indicated if the scenario assumed that land had been developed into kalos in previous years (sunk cost) and that only maintenance costs and labor were required to maintain the kalos previously developed

Table 14. Assumption on Base Livestock Numbers for Each Scenario

Scenario[a]	Cattle	Camels	Goats	Sheep
Scenario 1	16,700	1,900	10,200	7,200
Scenario 2	8,700	900	6,200	4,200
Scenario 3	16,700	1,900	10,200	7,200
Scenario 4	8,700	900	6,200	4,200
Scenario 5	16,700	1,900	10,200	7,200
Scenario 6	16,700	1,900	10,200	7,200
Scenario 7	8,700	900	6,200	4,200
Scenario 8	8,700	900	6,200	4,200
Scenario 9	16,700	1,900	10,200	7,200
Scenario 10	8,700	900	6,200	4,200
Scenario 11	16,700	1,900	10,200	7,200
Scenario 12	8,700	900	6,200	4,200

[a.] See text for scenario description.

Forage Available by Season

The figures for forage availability provided in Tables 15-17 reported the amount of forage in each season if none were used for grazing. This was reported this way because actual forage availability depended on the number and species of livestock using the forage as well as the storage in any given season and this was selected by the LP and was not known prior to the LP solution. Also, forage that was not used during a particular season could be "stored" or carried over to the next season.

Table 15. Assumptions on Grass Endowment[a] by Season Assuming Use is Equal to Zero

	Season			
Scenario	**LRS**	**CDC**	**SRS**	**LDS**
Scenario 1	614.0	491.2	740.8	592.7
Scenario 2	614.0	491.2	740.8	592.7
Scenario 3	153.5	122.8	185.2	148.2
Scenario 4	153.5	122.8	185.2	148.2
Scenario 5[b]	614.0	491.2	740.8	592.7
Scenario 6	614.0	491.2	740.8	592.7
Scenario 7	614.0	491.2	740.8	592.7
Scenario 8	614.0	491.2	740.8	592.7
Scenario 9[c]	153.5	122.8	185.2	148.2
Scenario 10	153.5	122.8	185.2	148.2
Scenario 11	153.5	122.8	185.2	148.2
Scenario 12	153.5	122.8	185.2	148.2

[a]All figures in kilogram per hectare of dry matter
[b]For scenarios 5-8, if brush is cleared, the grass endowment increases to; 1,615 in LRS, 1,292 in CDS, 1,949.4 in SRS and 1,559.5 in LDS on every hectare of land cleared.
[c]For scenarios 9-12, if brush is cleared and kalo is developed, the grass endowment increases to; 403.8 in LRS, 323 in CDS, 487.35 in SRS and 389.9 in LDS, on all hectares that are cleared of brush. For every hectare that has a kalo, it removes 403.8 in the LRS and deposits 500.7 in the LDS.

Table 16. Assumptions on Forb Endowment[a] by Season Assuming Use is Equal to Zero

	Season			
	LRS	CDC	SRS	LDS
Scenario 1	1,001.0	800.8	1,208.6	966.8
Scenario 2	1,001.0	800.8	1,208.6	966.8
Scenario 3	500.5	400.4	604.3	483.4
Scenario 4	500.5	400.4	604.3	483.4
Scenario 5[b]	1,001.0	800.8	1,208.6	966.8
Scenario 6	1,001.0	800.8	1,208.6	966.8
Scenario 7	1,001.0	800.8	1,208.6	966.8
Scenario 8	1,001.0	800.8	1,208.6	966.8
Scenario 9[c]	500.5	400.4	604.3	483.4
Scenario 10	500.5	400.4	604.3	483.4
Scenario 11	500.5	400.4	604.3	483.4
Scenario 12	500.5	400.4	604.3	483.4

[a]All figures in kilogram per hectare of dry matter.
[b]For scenarios 5-8, if brush is cleared, the forb endowment increases to; 1,615 in LRS, 1,284 in CDS, 1,512.8 in SRS and 1,210.2 in LDS on every hectare cleared.
[c]For scenarios 9-12, if brush cleared and kalo developed, forb endowment increases to; 807.5 in LRS, 646 in CDS, 759.2 in SRS and 607.4 in LDS on every hectare cleared.

Table 17. Assumptions on Browse Endowment[a] by Season Assuming Use is Equal to Zero

Scenario	Season			
	LRS	**CDC**	**SRS**	**LDS**
Scenario 1	49.0	23.0	27.0	17.0
Scenario 2	49.0	23.0	27.0	17.0
Scenario 3	39.2	18.4	21.6	13.6
Scenario 4[b]	39.2	18.4	21.6	13.6
Scenario 5	49.0	2.3	2.7	1.7
Scenario 6	49.0	23.0	27.0	17.0
Scenario 7	49.0	23.0	27.0	17.0
Scenario 8	49.0	23.0	27.0	17.0
Scenario 9	49.0	23.0	27.0	17.0
Scenario 10	49.0	23.0	27.0	17.0
Scenario 11	49.0	23.0	27.0	17.0
Scenario 12	49.0	23.0	27.0	17.0

[a]All figures in kilogram per hectare of dry matter.
[b]For Scenarios 4-12, if brush is cleared and kalo developed, browse is reduces to; 4.9 in LRS, 2.3 in CDS, 2.7 in SRS and 1.7 in LDS on every hectare cleared.

There was also a certain loss assigned to each forage species for each season due to trampling, leaf loss, and other factors based on the number of months in the season and an estimated monthly loss rate (Coppock 2014). The following equations indicated how forage availability and carry over were calculated for each forage species and season:

(16) $LRS_{AVAIL_m} = \left[MONTHS_{LRS} * LOSS_{LRS_m} * PROD_{LRS_m}\right] \; \forall\, m$

(17) $LRS_{CO_m} = \left[LRS_{AVAIL_m} - \sum_n USE_{LRS_{nm}}\right] \; \forall\, m$

(18) $CDS_{AVAIL_m} = \left[MONTHS_{CDS} * LOSS_{CDS_m} * LRS_{CO_m}\right] \; \forall\, m$

(19) $CDS_{CO_m} = \left[CDS_{AVAIL_m} - \sum_n USE_{CDS_{nm}}\right] \; \forall\, m$

(20) $SRS_{AVAIL_m} = \left[MONTHS_{SRS} * LOSS_m * CDS_{CO_m} + PROD_{SRS_m}\right] \; \forall\, m$

(21) $SRS_{CO_m} = \left[SRS_{AVAIL_m} - \sum_n USE_{SRS_{nm}}\right] \; \forall \, m$

(22) $LDS_{AVAIL_m} = \left[MONTHS_{LDS} * \; LOSS_m * \; SRS_{CO_m}\right] \; \forall \, m$

(23) $LDS_{CO_m} = 0 \;\; \forall \, m$

where

LRS, *CDS*, *SRS*, and *LDS* = the long rainy season, cool dry season, short rainy season, and long dry season, respectively.

MONTHS = number of months in the indicated season.

$LOSS_m$ = monthly loss rate due to trampling, etc. for the m^{th} forage species (s= 1, 2, 3 with 1 = grass, 2 = forbs, and 3= browse).

$PROD_m$ = production in the indicated season for the m^{th} forage species.

USE_{nm} = Use (amount consumed in grazing) by the n^{th} livestock type for the m^{th} forage species during the indicated season.

$AVAIL_m$ = forage available at beginning of the indicated season for the m^{th} forage species.

CO_m = forage available at the end of the indicated season and available to be carried over (stored) for the next season for the m^{th} forage species.

The value of equations (16) through (22) are greater than or equal to zero. In other words, a negative value for forage was not allowed.

Forage loss per month was calculated at 10 percent for grass and forbs (Coppock 2014). For browse, a set amount of loss was assumed to be 10.2 percent in the LRS, 14.5 percent in the CDS, 9.6 percent in the SRS, and 75.6% in the LDS (Coppock 2014). Consequently in the case of browse, *MONTHS* was set equal to one in equations (16), (18), (20), and (22) with $LOSS_3$ equaling the percentages provided in the previous sentence. The numbers reported in Tables 14-16 would essentially correspond to values for equations (16) – (23) if *USE* were set equal to zero in all cases.

Scenario 2

The second scenario (S2) assumed the number of livestock in Harweyu was at their actual current level (Table 14). Current livestock numbers were nearly half of estimated capacity as a result of a 2011 drought and the time it takes to restock (Table 14). All of the other constraints from S1 (besides livestock numbers) were constant with S1. Restocking can take years following a drought due to the devastating nature of droughts that kill livestock and leave many people in the Borana Plateau at or near destitution as a result. A lack of available capital and the fact that much of the restocking occurs through natural expansion of herds over time was the reason that herd numbers were at less than full capacity. Examining economic conditions at current herd levels provided a picture of the current situation and how resources affected the ability to expand herd size and which species would have the best ability to expand during normal rainfall years after a drought.

Scenario 3

The third scenario (S3) used most of the same assumptions as S1, i.e., assumed full stocking of livestock but, forage production was assumed to be greatly reduced from S1 as a result of a dry year (Tables 15-17). The restrictions on forage for a dry year impacted milk production and forage availability as well as cropping. Grass production was reduced by 75 percent in the dry year and forbs by 50 percent compared to a normal rainfall year. Browse is more tolerant to drought than grass and forbs and was assumed to be reduced by only 20 percent in a dry year. Milk production for cattle was cut in half with the number of lactating cows also reduced by 10 percent (Coppock 2014). The number of lactating goats, sheep and camels did not change from S1 but milk production for female sheep and goats was reduced 25 percent compared to S1. There were no harvested crops because of the drought was assumed to result in no crop production. However, the labor required to plant and nurture crops was assumed to be incurred up until the time to harvest (harvest labor not needed because no crop resulted). This was consistent with the experiences of the Boran in the Borana Plateau because they are required to prepare the land and plant without knowing if there will be enough rainfall to actually grow the crop.

Scenario 4

The fourth scenario (S4) imposed the same dry year restrictions and assumption on milk production and forage availability as S3. However, all of the other assumptions made for S2 (current livestock numbers) were also applied (Tables 14-17). The intent of S4 was to capture how a dry year impacted Boran pastoralists differently if they were either at full capacity (i.e., S3) or were still recovering from a previous drought when the next drought hit (S4).

Scenario 5

The fifth scenario (S5) used the same parameters for forage available and livestock numbers as S1 (Tables 14-17). However, the difference between S1 and S5 was that excess labor was allowed to be used to clear brush. This resulted in potentially increasing availability of forage (especially grass) compared to S1 (Tables 15-17).

However, the estimated costs incurred as a result of brush clearing were also imposed on the model if the LP chose to use excess labor to clear brush. The LP model chose the herd composition based on the increased amount of grass and forbs available from clearing brush. In this scenario, the clearing of brush was assumed to be done manually using hand tools.

Scenario 6

The sixth scenario (S6) had the same assumptions for forage as S5 in that the base forage numbers are the same and excess labor was allowed to clear brush. However, in this scenario the number of livestock was not allowed to exceed current stocking rates; the same as S2 (Table 13).

Scenario 7

The seventh scenario (S7) had the same amount of forage available and the same limits on livestock numbers as S1 (Tables 14-17). However, excess labor was allowed to be used to clear brush as it did in S5 and S6. But, in this scenario excess labor was also allowed to develop kalo(s). Additional costs to develop kalos were incurred and the model based on the change in forage availability chose the livestock complement.

Scenario 8

The eighth scenario (S8) had the same parameters as S7 but it assumed the same limits on livestock as S2 (Table 14). The model again chose the livestock complement based on profitability of livestock and livestock products subject to forage, labor, and nutritional constraints (Tables 15-17).

Scenario 9

The ninth scenario (S9) used the same assumptions on the limits for livestock numbers as in S1 (Table 14), but also used the same assumptions on forage production for a dry year as described in S3 (Tables 15-17). That was to say that milk production and cropping in this scenario were the same as S3. The nuance of this scenario was that it assumed that brush clearing had already taken place before the dry year came. This scenario tested if the increased forage production from clearing brush would sustain the livestock at full capacity. To do this, the LP was essentially allowed to select how much land would have needed to be cleared of brush prior to the drought year to continue to sustain livestock numbers at full capacity during a single drought year. Due to the assumption of land already having been cleared (previous sunk cost), the cost of brush clearing was reduced to 240.00 Birr/ha (maintenance cost only) as well as the amount of labor needed to clear brush was reduced to only 10 percent of what would be needed to originally clear brush (10 percent was an estimate of the labor needed to simply maintain previously cleared land free of brush encroachment).

Scenario 10

The 10th scenario (S10) had the same assumptions as S9 with respect to forage availability (Tables 15-17). This scenario also assumes that land has been cleared previously and that the only current costs associated with the cleared land were out-of-pocket costs and labor required to simply maintain it to be free of brush encroachment (same as in S9). In this scenario livestock numbers were assumed to limited to the same numbers as in S2 (Table 14); at current stocking rates. This scenario indicated if the Boran had already been endowed with enough clearing land to maintain current livestock levels how much land would that need to be. S10 also indicated the other impacts a drought would have on the community beyond simply the ability to keep the current number of livestock alive during the drought.

Scenario 11

The 11th scenario (S11) had the same available forage and livestock numbers as S9 (Tables 14-17) only instead of just an endowment of land cleared of brush, this scenario also allowed for an endowment of kalo that would preserve forage for the LDS. The costs and labor required for maintaining cleared were the same as assumed in S9. In this scenario, kalo maintenance costs were considered to be 150.00 Birr/ha. This scenario determined how much land clearing and kalo development would have been needed to be undertaken previous to a drought to maintain livestock numbers at full capacity during a one-year drought event. S11 also indicated the other impacts a drought would have on the community beyond simply the ability to keep livestock numbers at full capacity during a drought.

Scenario 12

The 12th scenario (S12) had the same available forage and kalo development numbers, as S11 only in this scenario the limits on livestock number were set the same as S2 (current numbers). This scenario determined how much land clearing and kalo development would have been needed to be undertaken previous to a drought to maintain current livestock numbers during a one-year drought event. S12 also indicated the other impacts a drought would have on the community beyond simply the ability to keep livestock numbers at their current levels during a drought.

CHAPTER 4

RESULTS

The LP model was designed to calculate the anticipated returns the community and households could expect under the various scenarios described in Chapter 3. The scenarios were designed to be reflective of existing conditions and the effects of drought and climate change in the study area. The scenarios attempted to mimic the impact climate change might have on the pastoralist system as well as to describe the herd complement (number and species) that would maximize livelihoods based on forage endowments during normal rainfall and drought years.

The LP demonstrated the frailty of the current system and the results for the various scenarios showed how specific interventions (brush clearing and kalo development) could help mitigate many of the most damaging effects of drought on the pastoralist way of life in the Borana Plateau. The household makeup in this study was typical for the area and family household expenses (i.e. healthcare, education) were also typical for the region. Assumptions about other household costs (pantry items) were also consistent with those in the study area.

The LP was not designed to directly calculate the precise amount of a food deficit and subsequent food aid needed to sustain the human population under the various scenarios. Rather, the scenarios were designed to show what changes would be required to minimize the need for food aid when the humans in the study area were taken to the edge of collapse every time a drought occurs. The LP was also designed to show the most restrictive components of the system or, in other words, the most limiting resources to success in the Boran pastoralist system. This information provided insight into what interventions would be most sustainable in reducing the dependency of people in the study area on food aid during droughts.

The LP results provided estimates for community and household income (objective function) under the various scenarios (often reported in the tables in scientific notation). The quantities of food raised and purchased, number of livestock, and forage utilization under each scenario will be reported in this chapter. These variables change across the various scenarios as the LP optimizes income subject to available livestock and forages resources and human nutritional requirements. The results for the different scenarios demonstrated the impact of different actions the scenarios assumed the community could take to become more resilient during periods of drought. By comparing and contrasting the LP results for the different scenarios, an understanding was gained into how different interventions might reduce the need for food aid in the study area as well as the potential impact of the interventions on the future of the pastoral system in the Borana Plateau. After describing the results for S1, the discussion of the remaining scenarios provided explanations of the changes in forage needs, livestock complement, food cost (food aid) and overall community profit associated with the remaining scenarios. Basic numerical results from the LP for the scenarios including the objective function (Tables 18 and 19), sources of revenue, costs, livestock complement (Table 20), grass demand (Table 21), forage utilization by season (Tables 22-33), milk and maize used (food purchases) (Table 34), and land either cleared or developed into kalos (Table 35). Numbers given in parentheses in these tables indicated that the value was negative.

Table 18. Summary of Expenses and Revenue for the Entire Community of Harweyu for Each Scenario Reported in Birr

	Scenarios											
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Objective Function	1.98E+07	5.41E+06	1.40E+07	1.42E+07	1.98E+07	5.41E+06	1.98E+07	5.41E+06	1.08E+07	1.30E+07	1.00E+07	1.26E+07
Livestock Revenue	8.79E+06	5.08E+06	2.37E+06	2.12E+06	8.79E+06	5.08E+06	8.79E+06	5.08E+06	5.55E+06	3.22E+06	5.65E+06	3.22E+06
Crop Revenue	1.44E+06	1.44E+06	-	-	1.44E+06	1.44E+06	1.44E+06	1.44E+06	-	-	-	-
Milk Revenue	1.98E+07	8.72E+06	-	-	1.98E+07	8.72E+06	1.98E+07	8.72E+06	3.72E+06	5.30E+05	3.72E+06	5.30E+05
Livestock Costs	3.31E+06	2.12E+06	7.44E+05	6.82E+05	3.31E+06	2.12E+06	3.31E+06	2.12E+06	1.85E+06	1.05E+06	1.88E+06	1.05E+06
Crop Costs	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04	3.54E+04
Household Costs	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06	1.53E+06
Food Costs	5.35E+06	6.15E+06	1.40E+07	1.40E+07	5.35E+06	6.15E+06	5.35E+06	6.15E+06	1.22E+07	1.27E+07	1.22E+07	1.27E+07
Brush Clearing Costs	-	-	-	-	-	-	-	-	4.49E+06	1.41E+06	3.09E+06	6.59E+05
Kalo Costs	-	-	-	-	-	-	-	-	-	-	6.82E+05	3.65E+05

Table 19. Summary of Expenses and Revenue per Household in Harweyu for Each Scenario Reported in Birr

	Scenarios											
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Objective Function	51,725.06	14,120.19	(36,506.2)	(36,981.08)	51,726.37	14,120.19	51,726.37	14,120.19	(28,206.13)	(34,004.96)	(26,141.42)	(33,001.70)
Livestock Revenue	22,925.18	13,256.36	6,179.65	5,536.31	22,925.18	13,256.36	22,925.18	13,256.36	14,473.63	8,395.30	14,731.83	8,395.30
Crop Revenue	3,757.34	3,757.34	-	-	3,757.34	3,757.34	3,757.34	3,757.34	-	-	-	-
Milk Revenue	51,744.34	22,764.04	-	-	51,744.34	22,764.04	51,744.34	22,764.04	9,696.45	1,383.43	9,696.45	1,383.43
Livestock Costs	(8,638.85)	(5,518.59)	(1,942.41)	(1,778.63)	(8,637.55)	(5,518.59)	(8,637.55)	(5,518.59)	(4,832.98)	(2,750.68)	(4,898.79)	(2,750.68)
Crop Costs	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	(92.36)	92.36
Household Costs	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)	(4,000.00)
Food Costs	(13,970.57)	(16,046.60)	(36,651.01)	(36,648.14)	(13,970.57)	(16,046.60)	(13,970.57)	(16,046.60)	(31,726.81)	(33,265.75)	(31,726.81)	(33,265.75)
Brush Clearing Costs	-	-	-	-	-	-	-	-	(11,723.99)	(3,675.02)	(8,072.25)	(1,718.36)
Kalo Costs	-	-	-	-	-	-	-	-	-	-	(1,779.55)	(953.28)

Table 20. Livestock Complement (Number of Head and Species) for Harweyu Under the Various Scenarios

	Scenarios											
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cattle	16,700	8,700	5,045	5,048	16,700	8,700	16,700	8,700	16,700	8,700	16,700	8,700
Camels	1,583	900	1,266	900	1,583	900	1,583	900	796	900	942	900
Goats	7,583	6,200	-	-	7,583	6,200	7,583	6,200	-	-	-	-
Sheep	5,384	4,200	-	-	5,384	4,200	5,384	4,200	-	-	-	-
Equines	250	240	240	240	240	240	240	240	240	240	240	240

Table 21. Total Grass Demand for Livestock Under Each Scenario and Season of the Year Reported in Kilograms of Dry Matter

	Scenarios											
Season	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
LRS	6.33E+06	3.46E+06	2.01E+06	2.01E+06	6.52E+06	3.46E+06	6.52E+06	3.46E+06	6.42E+06	3.39E+06	6.42E+06	3.39E+06
CDS	8.14E+06	4.32E+06	2.53E+06	2.53E+06	8.14E+06	4.32E+06	8.14E+06	4.32E+06	8.05E+06	4.26E+06	8.05E+06	4.26E+06
SRS	3.28E+06	1.77E+06	1.02E+06	1.02E+06	3.27E+06	1.77E+06	3.27E+06	1.77E+06	3.18E+06	1.70E+06	3.18E+06	1.70E+06
LDS	1.05E+07	5.71E+06	3.16E+06	3.16E+06	1.05E+07	5.71E+06	1.05E+07	5.71E+06	9.95E+06	5.29E+06	9.95E+06	5.29E+06

Table 22. Grass, Forbs, and Browse Demand by Livestock Species for S1 Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	**CDS**	**SRS**	**LDS**
Grass:				
Cattle	6,332,005	7,917,002	3,087,997	9,731,007
Camels	5,831	9,163	4,999	1,421
Equines	91,500	137,500	91,500	229,000
Goats	23,046	28,247	23,789	287,722
Sheep	68,051	20,106	70,296	239,296
Forbs:				
Cattle	334,000	416,999	312,006	103,006
Camels	5,831	9,163	4,999	12,496
Equines	5,000	7,500	5,000	12,500
Goats	28,248	24,532	28,999	16,357
Sheep	35,148	86,745	35,897	30,658
Browse:				
Camels	574,810	878,876	593,138	1,163,782
Goats	181,410	296,648	188,099	228,989
Sheep	62,818	112,170	65,058	109,930

Table 23. Grass, Forbs, and Browse used in S2 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	3,298,709	4,124,426	1,608,717	5,069,447
Camels	3,316	5,210	2,842	808
Equines	87,840	132,000	87,840	219,840
Goats	18,842	23,095	19,449	235,234
Sheep	53,084	39,085	54,835	186,665
Forbs:				
Cattle	174,000	217,239	162,542	53,662
Camels	3,316	5,210	2,842	7,106
Equines	48,000	7,200	4,800	12,000
Goats	23,095	20,057	23,709	13,373
Sheep	27,418	67,666	28,001	23,915
Browse:				
Camels	326,842	499,737	337,263	661,737
Goats	148,316	242,532	153,785	187,215
Sheep	49,001	87,499	50,749	85,751

Table 24. Grass, Forbs, and Browse used in S3 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	1,913,039	2,391,901	932,952	2,939,952
Camels	4,665	7,330	3,999	1,137
Equines	87,840	132,000	87,840	219,840
Forbs:				
Cattle	100,909	125,985	94,264	31,120
Camels	4,665	7,330	3,999	9,997
Equines	4,800	7,200	4,800	12,000
Browse:				
Camels	459,848	703,101	474,510	931,025

Table 25. Grass, Forbs, and Browse used in S4 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	1,913,872	2,392,943	933,358	2,941,232
Camels	3,316	5,210	2,842	808
Equines	87,840	132,000	87,840	219,840
Forbs:				
Cattle	100,953	126,039	94,305	31,134
Camels	3,316	5,210	2,842	7,106
Equines	4,800	7,200	4,800	12,000
Browse:				
Camels	326,842	499,737	337,263	661,737

Table 26. Grass, Forbs, and Browse used in S5 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	6,332,005	7,917,002	3,087,997	9,731,007
Camels	5,831	9,163	4,999	1,421
Equines	87,840	132,000	87,840	219,840
Goats	23,046	28,248	23,789	287,722
Sheep	68,051	50,106	70,296	239,296
Forbs:				
Cattle	334,000	416,999	312,006	103,006
Camels	5,831	9,163	4,999	12,496
Equines	4,800	7,200	4,800	12,000
Goats	28,248	24,532	28,999	16,357
Sheep	35,148	86,745	35,897	30,658
Browse:				
Camels	574,810	878,876	593,138	1,163,782
Goats	181,410	296,648	188,099	228,989
Sheep	62,818	112,170	65,058	109,930

Table 27. Grass, Forbs, and Browse used in S6 by Livestock Species Reported in Kilograms of Dry Matter by Season

	Season			
Species	**LRS**	**CDS**	**SRS**	**LDS**
Grass:				
Cattle	3,298,709	4,124,426	1,608,717	5,069,447
Camels	3,316	5,210	2,842	808
Equines	87,840	132,000	87,840	219,840
Goats	18,842	23,095	19,449	235,234
Sheep	53,084	39,085	54,835	186,665
Forbs:				
Cattle	174,000	217,239	162,542	53,662
Camels	3,316	5,210	2,842	7,106
Equines	4,800	7,200	4,800	12,000
Goats	23,095	20,057	23,709	13,373
Sheep	27,418	67,666	28,001	23,915
Browse:				
Camels	326,842	499,737	337,263	661,737
Goats	148,316	242,532	153,785	187,215
Sheep	49,001	87,499	50,749	85,751

Table 28. Grass, Forbs, and Browse used in S7 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	**CDS**	**SRS**	**LDS**
Grass:				
Cattle	6,332,005	7,917,002	3,087,997	9,731,007
Camels	5,831	9,163	4,999	1,421
Equines	87,840	132,000	87,840	219,840
Goats	23,046	28,248	23,789	287,722
Sheep	68,051	50,106	70,296	239,296
Forbs:				
Cattle	334,000	416,999	312,006	103,006
Camels	5,831	9,163	4,999	12,496
Equines	4,800	7,200	4,800	12,000
Goats	28,248	24,532	28,999	16,357
Sheep	35,148	86,745	35,897	30,658
Browse:				
Camels	574,810	878,876	593,138	1,163,782
Goats	181,410	296,648	188,099	228,989
Sheep	62,818	112,170	65,058	109,930

Table 29. Grass, Forbs, and Browse used in S8 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	3,298,709	4,124,426	1,608,717	5,069,447
Camels	3,316	5,210	2,842	808
Equines	87,840	132,000	87,840	219,840
Goats	18,842	23,095	19,449	235,234
Sheep	53,084	39,085	54,835	186,665
Forbs:				
Cattle	174,000	217,239	162,542	53,662
Camels	3,316	5,210	2,842	7,106
Equines	4,800	7,200	4,800	12,000
Goats	23,095	20,057	23,709	13,373
Sheep	27,418	67,666	28,001	23,915
Browse:				
Camels	326,842	499,737	337,263	661,737
Goats	148,316	242,532	153,785	187,215
Sheep	49,001	87,499	50,749	85,751

Table 30. Grass, Forbs, and Browse used in S9 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	6,332,005	7,917,002	3,087,997	9,731,007
Camels	2,931	4,606	2,512	714
Equines	87,840	132,000	87,840	219,840
Forbs:				
Cattle	334,000	416,999	312,006	103,006
Camels	2,931	4,606	2,512	6,281
Equines	4,800	7,200	4,800	12,000
Browse:				
Camels	288,923	441,759	298,135	584,964

Table 31. Grass, Forbs, and Browse used in S10 by Livestock Species Reported in Kilograms of Dry Matter by Season

	Season			
Species	**LRS**	**CDS**	**SRS**	**LDS**
Grass:				
Cattle	3,298,709	4,124,426	1,608,717	5,069,447
Camels	3,316	5,210	2,842	808
Equines	87,840	132,000	87,840	219,840
Forbs:				
Cattle	174,000	217,239	162,542	53,662
Camels	3,316	5,210	2,842	7,106
Equines	4,800	7,200	4,800	12,000
Browse:				
Camels	326,842	499,737	337,263	661,737

Table 32. Grass, Forbs, and Browse used in S11 by Livestock Species Reported in Kilograms of Dry Matter by Season

	Season			
Species	**LRS**	**CDS**	**SRS**	**LDS**
Grass:				
Cattle	6,332,005	7,917,002	3,087,997	9,731,007
Camels	3,471	5,454	2,975	846
Equines	87,840	132,000	87,840	219,840
Forbs:				
Cattle	334,000	416,999	312,006	103,006
Camels	3,471	5,454	2,975	7,439
Equines	4,800	7,200	4,800	12,000
Browse:				
Camels	342,162	523,160	353,072	692,754

Table 33. Grass, Forbs, and Browse used in S12 by Livestock Species Reported in Kilograms of Dry Matter by Season

Species	Season			
	LRS	CDS	SRS	LDS
Grass:				
Cattle	3,298,709	4,124,426	1,608,717	5,069,447
Camels	3,316	5,210	2,842	808
Equines	87,840	132,000	87,840	219,840
Forbs:				
Cattle	174,000	217,239	162,542	53,662
Camels	3,316	5,210	2,842	7,106
Equines	4,800	7,200	4,800	12,000
Browse:				
Camels	326,842	499,737	337,263	661,737

Table 34. Milk and Maize Sales and Purchases Under Each of the Twelve Scenarios with Milk Reported in Liters and Maize in Kilograms[a]

Scenario	Food Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S1	Milk	(16569.53)	(16569.53)	(16569.53)	316571.7	316571.68	205523.02	205523.02	205523.02	50058.72	22296.55	(16569.53)	(16569.53)
	Maize	(43337.11)	(43337.11)	(43337.11)	(43337.11)	(43337.11)				(33774.16)	(43337.11)	(43337.11)	(43337.11)
S2	Milk	(24549.53)	(24549.53)	(24549.53)	149003.08	149003.08	91151.38	91151.38	91151.38	10161.00	(4301.93)	(24549.53)	(24549.53)
	Maize	(43337.11)	(43337.11)	(43337.11)	(43337.11)	(43337.11)				(33774.16)	(43337.11)	(43337.11)	(43337.11)
S3	Milk	(31903.35)	(31903.35)	(31903.35)	(5416.68)	(5416.68)	(14245.70)	(14245.70)	(14245.70)	(26606.01)	(28813.27)	(31903.35)	(31903.35)
	Maize	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)
S4	Milk	(31902.77)	(31902.77)	(31902.77)	(5404.57)	(5404.57)	(14237.43)	(14237.43)	(14237.43)	(26603.13)	(28811.35)	(31902.77)	(31902.77)
	Maize	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)
S5	Milk	(16569.53)	(16569.53)	(16569.53)	316571.68	316571.68	205523.02	205523.02	205523.02	50058.72	22296.55	(16569.53)	(16569.53)
	Maize	(43337.11)	(43337.11)	(43337.11)	(43337.11)	(43337.11)				(33774.16)	(43337.11)	(43337.11)	(43337.11)
S6	Milk	(24549.53)	(24549.53)	(24549.53)	149003.08	149003.08	91151.38	91151.38	91151.38	10161.00	(4301.93)	(24549.53)	(24549.53)
	Maize	(43337.11)	(43337.11)	(43337.11)	(43337.11)	(43337.11)				(33774.16)	(43337.11)	(43337.11)	(43337.11)
S7	Milk	(16569.53)	(16569.53)	(16569.53)	316571.68	316571.68	205523.02	205523.02	205523.02	50058.72	22296.55	(16569.53)	(16569.53)
	Maize	(43337.11)	(43337.11)	(43337.11)	(43337.11)	(43337.11)				(33774.16)	(43337.11)	(43337.11)	(43337.11)
S8	Milk	(24549.53)	(24549.53)	(24549.53)	149003.08	149003.08	91151.38	91151.38	91151.38	10161.00	(4301.93)	(24549.53)	(24549.53)
	Maize	(43337.11)	(43337.11)	(43337.11)	(43337.11)	(43337.11)				(33774.16)	(43337.11)	(43337.11)	(43337.11)
S9	Milk	(28844.03)	(28844.03)	(28844.03)	58824.71	58824.71	29601.38	29601.38	29601.38	(11310.28)	(18616.11)	(28844.03)	(28844.03)
	Maize	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)
S10	Milk	(30944.03)	(30944.03)	(30944.03)	14727.71	14727.71	(496.42)	(496.42)	(496.42)	(21809.68)	(25615.71)	(30944.03)	(30944.03)
	Maize	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)

Table 34 Continued. Milk and Maize Sales and Purchases Under Each of the Twelve Scenarios with Milk Reported in Liters and Maize in Kilograms[a]

Scenario	Food Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S11	Milk	(28844.03)	(28844.03)	(28844.03)	58824.71	58824.71	29601.38	29601.38	29601.38	(11310.28)	(18616.11)	(28844.03)	(28844.03)
	Maize	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)
S12	Milk	(30944.03)	(30944.03)	(30944.03)	14727.71	14727.71	(496.42)	(496.42)	(496.42)	(21809.68)	(25615.71)	(30944.03)	(30944.03)
	Maize	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)	(38137.17)

[a] Numbers reported in parentheses indicate food needing to be purchased in the amount indicated for that month (a food deficit existed in the community for that month for the indicated scenario). Numbers not in parentheses indicate the amount of the food type that was sold by the community during that month for the indicated scenario (i.e., more of the indicated food type was available that month than was required to meet the nutritional requirements of the community and, thus, was available to be sold in local markets.

Table 35. Total Number of Hectares Modified in Harweyu for Each Scenario

	Scenario											
Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Brush Cleared	-	-	-	-	-	-	-	-	18,721	5,869	12,890	2,744
Kalo Developed	-	-	-	-	-	-	-	-	-	-	2,273	1,218

Scenario 1

S1 was used as a base scenario because it showed how the system would operate when there was full stocking of livestock and a normal rainfall year was experienced. S1 demonstrated the situation for the community if drought had not been experienced for several years and livestock numbers had been re-stocked to the full capacity that could be supported by current forage resources during a normal rainfall year (Table 14). S1 basically represented the capacity of the system given current forage availability in the absence of drought. Consequently, it demonstrated economic conditions for the community under the best of times without any interventions such as brush clearing or kalo development.

This scenario showed a positive objective function (profit) of 51,725 Birr per household, or about $2,500 USD per household (Tables 18 and 19). The profit for the households came after meeting their nutritional requirements from the revenue generated from their different enterprises. Consequently, this amount (51,725 Birr) would be available for expenditures other than food, school, medical, and other (e.g., clothing expenses) for households in the study area. The results for S1 indicated that the members of the community would be relatively prosperous in that they would be achieving a standard of living slightly above the $2/day/adult poverty line defined by the World Bank even after all “normal” expenses.

Livestock revenue was positive for S1 at an average of 22,925 Birr per household (Table 19). Under S1, the pastoralists were able to sell animals when market prices were stable and not influenced by people needing to offload animals for money during periods of drought. Under this scenario, there was enough rainfall to grow the crops that were planted and subsequently harvested. As a result, crop revenue was calculated at 3,757 Birr per household (Table 19).

The relative abundance of grass assumed in S1, compared to drought year scenarios, allowed the pastoralists in Harweyu to be fully stocked with livestock (Table 19). The milk offtake for this scenario indicated that under the conditions described for S1 that there was an excess of milk, especially cow milk, above the nutritional needs of the community (Table 35). This would have allowed the Boran in Harweyu to sell milk, resulting in estimated revenue of 51,744 Birr annually per household from milk sales (Table 20).

Livestock costs were the highest for S1 of all the scenarios at 8,638 Birr per household (Table 19). High livestock costs reflected that the system was at capacity and there was enough forage to maintain the size of the herd at that level (Table 20). Crops costs and household cost were consistent throughout all the scenarios as the community plants crops regardless of whether or not there was a harvest.

The time of year that was indicated in the results for S1 as the most restrictive was, not surprisingly, the LDS (Tables 21 and 22). During the LDS season camels are the only species lactating and there was no crop to harvest. This was also the longest season of the year and there were no new endowment on forage (i.e. forage does not grow during the LDS). So, the only forage available during the LDS is what was been carried over from the previous season (not consumed also referred to as stored).

Food purchases for S1 were generally made during the LDS to meet the nutritional requirements that the human population (Table 34). In this scenario, the food costs (food purchased) of 13,970 Birr represented the nutrition that needed to be purchased above what can be produced by the community through either milk offtake or crop harvest (Table 19). This also would have represented the amount of food aid needed to maintain daily energy requirements if the community had no money to buy food. However, because the objective function was positive, it indicated there was enough income generated by the community to afford to by this amount of food (i.e., no food aid was required).

There was an end-of-the-year forage surplus that suggested that even more cattle could be brought into the system to take advantage of available grass (Table 21). However, all the scenarios have an upper bound on the number of each livestock species that could be in Harweyu (Table 14).

S1 demonstrated that the system, when fully stocked and with a normal rainfall, year is self-sustaining. That is to say, the revenue generated from the various activities is above the cost of production and also the cost of buying food when it cannot be produced. There was enough forage to maintain the livestock numbers at capacity.

Scenario 2

S2 was used to show how the current livestock complement would fare in a normal year and what would happen to overall income and the need for food aid as compared to when Harweyu is fully stocked (S1). Many livestock in Harweyu died during the drought of 2011 and the community has not yet recovered from that drought. Consequently, S2 mimicked the current situation for the community. That was, it demonstrated how the communities of the Borana Plateau would have fared during rebuilding years following a serious drought such as the one experienced in 2011.

The objective function for S2 was much less than for S1 (51,725 Birr per household for S1 compared to 14,120 Birr per household for S2) (see Tables 18 and 19). Revenue from the sale of livestock was also less than S1 at 13,256 Birr per household as was milk revenue at 22,764 Birr per household (Table 19). Although these revenue streams were down compared to the revenue estimated for S1, livestock costs were also down. This was a result of the current stocking rate of livestock, which is nearly half of estimated capacity (Table 20).

The months in which the Boran could sell milk and needed to buy milk were the same as in S1 (Table 34), with crop and household costs remaining the same in all scenarios. Food purchases, or the amount of food needed to be purchased for the community to not have caloric deficiencies, as expected was higher for S2 than for S1 at 16,046 Birr per household (Table 19). The results for S2 showed that there was still enough revenue to purchase the food needed and still have profit at the end of the year even with the reduced number of livestock if there was normal rainfall. This meant that at current stocking rates, the pastoralist system in Harweyu could be self-sustaining and provide a profit for the community. As a result, the re-stocking of the livestock herd would be expected to continue.

The amount of forage available for S2 was in excess of S1 because of the reduced number of livestock in S2 compared to S1 (Tables 21 and 23). This showed that there was room for the herd to grow because forage and income would be available to do so. The upper bounds in this scenario were set to show the system at the current level of livestock and did not allow livestock numbers to grow beyond current numbers (although the LP could have reduced in number of livestock below current levels if forage resources had not been available to support the current herd size) (Table 20). However, because there was enough forage, the livestock numbers remained the same as they could be sustained.

S2 demonstrated that if there were enough years between droughts that the system could eventually rebuild herd numbers following a drought. Climate change appears to be resulting in droughts that are more severe and frequent in the Borana Plateau than they were in the past. This may be making the “normal” rebuilding pattern a thing of the past. That was, a drought killing significant numbers of livestock but then being followed by a number of years of normal rainfall in which rebuilding herds could have normally taken place would no longer the “normal” pattern). If this were the case, actions must be taken to improve the resilience of the system during droughts if even current levels of livestock numbers can be maintained. This resilience would depend on the ability to prevent more livestock from dying during droughts. Other scenarios considered in the analysis examined some possible alternatives that would possibly make the system more resilient during droughts (brush clearing and/or kalo development).

Scenario 3

S3 was the first scenarios introducing a simulation of a drought year in the study area. S3 was completed assuming the community had stocked livestock to full livestock capacity (Tables 14 and 20). This scenario showed the impact of a single drought year when the community has had enough drought-free years to become fully stocked again following a drought. The impacts on overall income and the need for food aid changed dramatically for S3 compared to S1 (S1 had same assumptions on livestock numbers but for a normal rainfall year) (Tables 18 and 19).

The objective function for this scenario displayed an average household deficit of 36,506 Birr (about $1,800 USD), with increased food costs compared to S1 having the most negative impact on income of the factors included in the calculation of the objective function (Tables 18 and 19). There was no revenue from a crop harvest to help offset food costs, as there was no harvest because a drought was assumed to have occurred. Livestock revenue dropped dramatically, compared to S1, from 22,925 Birr per household for S1 to 6,179 Birr per household for S3 (Table 19). This was the case even though more animals were offloaded in S3 than in S1 (Table 20). Livestock are a store of wealth for the Boran and in a drought year they needed to sell additional livestock above what they would in a normal year as a means to generate the revenue required to purchase food (maize). This drives the price of livestock down and the result was that less revenue was received in S3 than in S1 even though more livestock were sold in S3 than in S1 (Table 19).

Livestock costs for S3 were less than for S1 because there were fewer livestock in the system for S3 than S1 because grass production was down because of the drought (Table 20). The herd complement changes drastically for cattle compared to S1 as does the number of small ruminants (sheep and goats). Cattle numbers dropped from the capacity number of 16,700 head in S1 to 5,045 head in S3 (Table 20). This suggested that when the system is at full stocking for livestock, that a significant drought would result in massive die-offs of livestock. This fact was verified by the large drought losses that have been experienced in the Borana Plateau in past droughts.

The cattle that could be sold were sold at a significantly different price than they would have been during a normal rainfall year. The forage that was available, especially grass, is used to feed as many cattle as possible with a small amount of grass being used to support camels (Tables 19, 20, and 23). Camels are primarily browse eaters. Consequently, the LP selected camels as the species to utilize the available browse rather than sheep and goats because camels produced more milk than sheep or goats and were more valuable when they were sold than either sheep or goats (Table 20).

The LP model chose to maximize the number cattle and eliminate small ruminants from the system (no minimum requirement was forced into the system for any livestock other than equines for S3) because cattle produce greater value for the grass they use than do other livestock species in the Borana Plateau (Table 20). Although there will likely always going to be small ruminants in the Borana Plateau, this scenario demonstrated that cattle were the preferred livestock species in the system because they could generate the most return for the resources they used compared to the other livestock species.

Camel numbers dropped somewhat in S3 compared to S1 because more were sold in S3 than in S1, but the reduction in camel numbers from S1 to S3 was not huge (Table 20). This was because browse was not as impacted by the drought as grass and forbs were (Table 24). Camels are more drought-resistant than cattle and their diet accommodated a resource (browse) that was less impacted by the drought than was grass (Table 23). So, camels appeared to serve as a good method to at least partially mitigate the impact of drought in the study area. However, the LP indicated that there were not enough camels or browse to see the community through the drop in cattle numbers experienced in S3. This was indicated by the large negative value (income) for the objective function (Tables 18 and 18).

The community has a milk and maize deficit for all months of the year (Table 33). This means there was not enough milk offtake from livestock to meet the caloric requirements for the community. As a result, the members of the community needed to purchase milk every month. The milk and maize deficits showed the amount of food that would need to be purchased each month to meet the needs of the community. In contrast to S1 where revenue from good months allowed for the purchase of food in the deficit months (LDS), S3 has just enough revenue to cover operating expenses but not to buy the food needed (Tables 18, 19, and 34). This resulted in a food deficit of 36,651 Birr per household, which was basically the negative value of the objective function (Table 19).

S3 revealed just how fragile the system of the Borana Plateau is. A single year of drought, even when followed by enough normal rainfall years to restock the system, would result in severe suffering on the part of the human population and a drastic de-stocking of livestock. A single drought year can throw the system into a large food deficit and onto a large reliance on food aid to make up the difference needed for the caloric needs of the human population. This was the case even though energy (caloric) requirements were dropped by 10 percent in in S3 (a drought year) compared to S1 (a normal rainfall year). The loss of grass as a result of drought was indicated by this scenario at the most limiting resource in terms of success of the system, where success would be defined as sustainable and self-reliant community (Tables 21 and 24). S3 demonstrated the need for interventions to build the resilience of grass production as a means for mitigated the damage done by drought to the communities of the Borana Plateau.

Scenario 4

S4 was used to show the impact drought had on the community of Harweyu if they had not yet had time to fully restock following a previous drought (i.e., were at current livestock stocking levels). Because large numbers of livestock died during 2011 drought, the assumption on livestock numbers for S4 provided a good indication of the impact of the 2011 drought on the system if another drought year was experienced in relatively rapid succession. This was important because many believe that the effect of climate change is causing droughts to be more severe and frequent than in the past. S4 mimicked climate variability in the system and showed how overall income and the need for food aid changed when another drought occurs before the community can fully recover from a previous drought. Consequently, this scenario demonstrated the impact climate variability had on the goal for the system to become self-sustaining in the face of climate change.

Households would carry an average deficit of 36,981 Birr for S4 as opposed to a profit of 14,120 Birr for S2 (Tables 18 and 19). As was the case for S3 (another drought year scenario), there was no crop or milk revenue to the community realized for S4 because there were no harvested crops and no milk to sell due to the effects of the drought. In fact, there was both a milk and maize deficit for every month of the year under S4 (Table 34) resulting in the reported annual food cost of 36,648 Birr per household (about $1,800 USD). Purchases of maize were less for S4 than for S2 because the cost of maize rose during drought years and also because the model assumed a 10 percent decrease in the human energy requirements during a dry year compared to a normal rainfall year. The only source of revenue for the community in S4 was from livestock sales and, because the members of the community were forced to sell to generate revenue to purchase food, the prices for livestock were lower than during normal rainfall years (S2) and only 5,536 Birr was generated per household by livestock sales for S4 (Table 19).

Cattle numbers drop in S4 to 5,048 head from 8,700 in S2 and small ruminants are no longer carried in the system, for the same reasons as stated in S3 (Table 20). Camel numbers were the same as for S2 because the loss in browse resulting from the drought (20 percent loss in browse compared to S2) was not significant enough to warrant reductions in camel numbers. Consequently, for the purposes of this study it was assumed that there was enough browse in Harweyu to support the current stock of camels, even in a drought year.

Again, the binding constraint in the system was the available grass (Tables 21 and 25) to keep cattle alive and lactating. S4 demonstrated the pressure that increased frequency of drought has placed the system and community resulting in a downward spiral of reliance on food aid to meet the energy needs of the human population. Another drought would result in the community being left to start again with fewer animals than they had coming out of the last drought. This would make it increasingly difficult to rebuild the livestock herd after each successive drought. As a result, an increasing frequency of drought eats away at the ability of the system in the Borana Plateau to recover from drought. Without mitigation, climate change will likely reduce the resilience of the communities of the Borana Plateau and perhaps make them more dependent on outside food aid over time.

Scenario 5

S5 assumed the same livestock numbers and forage endowment as S1 (Table 14). S5 also assumed a normal rainfall year. However, this scenario allowed any excess labor to be used to clear brush, but at a cost (Table 35). Clearing brush resulted in improved grass production. When brush clearing is undertaken without building a fence to protect and save the grass for the LDS (kalo development), the grass is available throughout the year to livestock. Essentially, brush clearing created a larger, general grass endowment. However, the size of the cattle herd was not allowed to grow beyond full capacity (Tables 13 and 19). The purpose for not allowing the cattle herd to grow in the LP beyond the stated full capacity for the current forage endowment, even if brush clearing resulted in an expanded forage base, was to focus the analysis on sustainability/resilience of the community rather than herd expansion.

The results for S5 related to income as well as costs (objective function) remained unchanged from S1. The livestock complement was also unchanged from S1 (Table 19). This was because in a normal rainfall year there was no economic incentive for the Boran to incur the cost of clearing land in a normal rainfall when the livestock herd is already at full capacity (see Table 34). This was true because there was no possibility in S5 to increase the herd size past full capacity and there was enough forage during a normal rainfall year to sustain the livestock herd at full capacity without clearing brush to generate additional forage. S5 demonstrated that future interventions involving brush clearing would likely be undertaken to either build livestock numbers or to enhance the system's resilience to drought. As will be demonstrated in later scenarios, brush clearing can maintain livestock numbers (avoid sell-offs and die-offs) during droughts.

Consequently, the results of the analysis indicated that brush clearing and kalo development were defensive strategies against increasingly frequent and severe droughts rather than as methods to expand the livestock herd.

Scenario 6

S6 assumed the same livestock numbers and forage endowment as S2 and also assumed a normal rainfall year (Tables 19 and 26). This scenario allowed, as did S5, excess labor to be used to clear brush, at a cost, as a method to increase available grass. This scenario did not allow the herd size to grow past the current number of livestock in Harweyu.

The overall income and cost for the community (objective function) were the same as in S2, as was the livestock complement (Tables 17, 18, and 19). This generated essentially the same overall conclusions as for S5; there is no economic incentive to clear brush in a normal year, regardless of the stocking rate unless it is to expand the livestock herd. If the goal is increased community resilience to drought, interventions aimed at expanding the local livestock herd need to show the herd could be expanded during good years and then maintained during drought years as a result of clearing brush. Again, this scenario was only interested in the sustainability of the current system. As a result, livestock numbers were limited to their current levels and, in this case, there was plenty of forage for the livestock in a normal rainfall year (Tables 20 and 26).

Scenario 7

S7 was a scenario that assumed livestock numbers were at full capacity (Table 14) and the forage endowment was the same as S1 (assumed a normal rainfall year). This scenario allowed excess labor to not only be used to clear brush but also to develop kalo(s) to serve as a forage reserve for grass into the LDS.

The overall income and cost for the community (objective function) remained the same as for S1. The livestock complement also remained constant with S1 (Table 20). Due to the additional cost above brush clearing (Table 35) no land was developed into a kalo under this scenario. This again resulted from a lack of incentives to incur the costs to clear land and/or develop kalos in a normal rainfall year because forage (particularly grass) was sufficient to support livestock numbers at full capacity. Consequently, no additional land needed to be cleared or kalos developed to generate additional grass for the livestock numbers that were limited in this scenario.

Scenario 8

S8 used the livestock numbers and forage endowment numbers from S2 and also assumed a normal rainfall year as did S2 (Table 14). This scenario allowed excess labor to clear brush and to develop kalo(s).

The overall income and costs for the community (objective function) were unchanged from S2. The livestock complement also remained unchanged from S2 (Table 20). The results for S8 indicated that no land would be cleared or kalo(s) developed for this scenario (Table 35). Again, this demonstrated that no economic incentive existed to clear brush and/or develop kalos in a normal rainfall year unless the purpose was to expand the livestock herd. To be sustainable, possible interventions aimed at expanding the local livestock herd would need to show the herd could be expanded in good years and then be maintained during drought years as a result of clearing brush and/or developing kalos. Again, this scenario was only interested in the sustainability/resiliency of the current system. As a result, livestock numbers were limited to be no more than their current levels. As such, there was plenty of forage for the livestock in this scenario (Tables 20 and 29).

Scenario 9

S9 was the first scenario testing the impact of clearing brush on the system when a drought event occurs (Table 13). Rather than requiring the model to impute the full cost of clearing brush for the drought year, this scenario assumed that brush had been cleared in non-drought years. Because the costs incurred in clearing land previously were sunk, this scenario considered only the out-of-pocket costs and labor requirements to maintain the cleared land to be free of new brush encroachment. This was done to test the impact of brush clearing on livestock numbers and how resilient the system would be in a drought if brush were cleared previously. Again, S9 and also S10-S12, considered the costs of previous brush clearing and kalo development as “sunk,” or essentially irrelevant to the economic decisions made in S9-S12 (Table 13). This allowed for an appraisal of the value of clearing brush as a means of drought mitigation rather than for herd expansion. In other words, these scenarios (S9-S12) demonstrated the value of clearing brush in good years solely as a means to reduce the looming impact of potential droughts.

S9, as was the case for S1 and S5, assumed a bound on the number of cattle to be 16,700 head (Table 14). Like S5, S9 also considered that brush clearing activities were or could have been undertaken by the community. The most important departure for S9 from S1 and S5 was that it assumed a drought year rather than a normal rainfall year (S1 and S5).

The overall income (objective function) for S9 showed a deficit of 28,206 Birr per household, or about $1,400 USD (Table 19), which was a large reduction in income, compared to S1. However, the income deficit in S9 was not as great as it was in drought years when brush had not been cleared (S3). This was due to the additional grass made available in areas cleared of brush. This “extra” grass would keep more cattle alive and lactating during a dry year compared to a drought year with no brush clearing (S3) (Table 20). Camel numbers dropped in this scenario (compared to S1) and, just as in S3, small ruminants were no longer in the system. For practical reasons already discussed there will likely always be small ruminants in the livestock system of the Borana Plateau, but the LP results demonstrated that brush clearing is a strategy that favored cattle and tended to eliminate small ruminants from the system.

The economic incentives for keeping as many cattle in the system as possible was the revenue stream they generated. Livestock revenue was increased from 6,179 Birr in S3 to 14,473 Birr in S9 (Table 19) due to more grass being available to keep cattle alive. Previously clearing enough brush kept cattle alive even though milk production declined because of the drought. As a result, enough milk was available for a surplus to be sold between April and August (Table 34). This meant there was milk revenue generated in S9 to partially offset the cost of buying maize during droughts (maize cost increases in a drought) and, consequently would reduce the need for food aid during a drought (Table 34). There was a maize deficit in each month of the year for S9 because there was no harvest during a drought. But, maize purchases were also tempered to a degree because the model assumed a 10 percent decrease in human energy requirements during a drought compared to a normal rainfall year.

The LP model indicated that 18,721 hectares of land would need to have been previously cleared of brush to keep cattle numbers at full capacity during a drought (Tables 19 and 35). The amount of land needed to be cleared of brush to keep cattle numbers at capacity in this scenario was a significant given it represented about 33 percent of the total land area of Harweyu (56,764 hectares total). However, the results for S9 suggested that a full complement of cattle (16,700) head would be able to survive one year of drought as a result of this level of brush clearing. That was to say that keeping cattle alive through a drought decreased the need for food aid compared to if no brush had been cleared (S9 vs. S3) (Table 19). Under S9, if the year following a drought year is a normal rainfall year, the system would experience no recovery time to rebuild livestock number because the system would keep existing livestock alive. Consequently, community income in the normal year following a drought would be assumed to reach the same level as reported for S1.

S9 showed that clearing brush, albeit on a relatively large amount of land, built resiliency into the system by reducing the time needed between drought years for the system to fully recover. S9 demonstrated that cattle were the most important livestock species in terms of their contribution to overall income for the community. The results also illustrated that if the cattle herd can be maintained through a one-year drought, short-term humanitarian relief may be required during the drought but the need for long-term food aid would reduce. The system can be successful (defined as self-sustaining) immediately following a single drought event, at least if the drought lasts only one year.

Scenario 10

S10 tested the impact brush clearing had on the current livestock numbers as define in S2 (Table 14). Rather than requiring the model to impute the full cost of clearing brush for the drought year, this scenario assumed that brush had been cleared in previous non-drought years. Because the costs incurred for previously clearing land were sunk, this scenario considered only the out-of-pocket costs and labor requirements to maintain the cleared land free of new brush encroachment. The LP model essentially selected how much land would need to have been previously cleared of brush to maintain livestock numbers at either full capacity (S9) or at current capacity (S10). This was done to test how existing land that had been cleared of brush could sustain livestock numbers during a drought. By so doing, S10 determined how resilient the system would be in a drought if brush were cleared and livestock numbers were only at their current levels (Table 14).

S10 basically allowed the community to not be set back, in terms of its livestock numbers, when they are in a rebuilding phase and another one-year drought is experienced. Because of the drought in 2011, livestock numbers in the study area are below full capacity and are in a re-building phase (Table 14). S10 essentially indicated how much land cleared of brush would be necessary to maintain the livestock herd through this rebuilding phase. It was expected that less land would be needed to be cleared than for S9 simply because fewer livestock would need to be supported through a drought at current levels compared to at full capacity and this was the case (Table 35). Consequently, S10 was a more conservative (less expensive) brush clearing strategy than

S9 and could be viewed as method to preserve the system at a level short of collapse but not at full capacity.

Overall income (objective function) showed a deficit of 34,004 Birr per household (about -$1,700 USD) (Table 19). There was no crop revenue for S10 because there was no crop harvested due to the drought. The previous land clearing provided enough grass to have a surplus of milk in April and May, which provided a small amount of revenue. In addition, the milk deficit for S10 was significantly reduced from June to August compared to S4 (Table 34). The community's energy requirements from milk were almost met for those months (Table 34). This suggested that brush clearing was able to keep livestock alive and to increase milk production in dry years well above what happened in S4 (a dry year with no brush clearing occurring) (Table 13).

The LP model indicated that 5,868 hectares of land or roughly 10 percent of the total hectares in Harweyu would have needed to have previously been cleared in order to maintain cattle numbers at current levels in a drought. By clearing this much land of brush, the cattle and camel numbers remained steady compared to S2. However, small ruminants were not selected by the LP to be in the system. This indicated that any available grass and browse would go to cattle and camels first and that the model preferred to have large animals in the system as they provided more milk and had higher sale values than sheep and goats.

The results for S10 showed that in a restocking year, when the Boran have suffered losses and are trying to rebuild their herds, brush clearing could have a huge impact on reducing the loss of livestock if another drought occurred. There would still be a need for food aid but, as was the case in S9, less food aid would be needed in the long-term because rebuilding would take place faster than if no brush clearing takes place.

The system would not suffer the livestock losses that would be experienced if no brush were cleared prior to a drought (see results for S4). As a result, the year following a drought would be more likely to see the community in better economic shape (more resilient) than if no brush clearing were undertaken. This implied that brush clearing helped the community to be more self-sustaining than if no brush was cleared.

Scenario 11

S11 was the first scenario for a drought year, which allowed kalo development on land that had been cleared of brush. The potential benefits of kalos have previously been discussed. But, essentially this scenario tested how a forage reserve (kalo) affected the ability to support livestock, especially cattle, through the LDS during drought years.

As was the case in scenario S9 and S10, rather than requiring the model to impute the full cost of clearing brush and/or kalo development in a drought year, this scenario assumed that brush had been cleared in non-drought years and that kalos had also been previously developed. Because the costs incurred in previously clearing land and developing kalos were sunk, this scenario considered only the out-of-pocket costs and labor requirements to maintain the cleared land and kalos to be free of new brush encroachment.

For this scenario, the LP model essentially selected how much land would need to have been previously cleared of brush and/or developed into kalos to maintain livestock numbers at either full capacity (S11) or at current capacity (S12). This was done to test how existing land that had been previously cleared of brush and/or developing into kalos could sustain livestock numbers during a drought. By so doing, S11 determined how resilient the system would be in a drought if brush and were cleared and/or kalos developed and livestock numbers were at full capacity (Table 14).

The overall income (objective function) for S11 was a deficit of 26,141 Birr per household (Table 19), or about $1,300 USD per household. However, this was an improvement over the deficit estimated for S3, which assumed the same conditions as for S11 but with no brush cleared or kalo(s) developed. Food costs remained the highest expenditure for the community in S11. There was no crop revenue because there was no harvested due to the drought. The increased amount of grass from clearing land and developing kalos that store grass into the LDS meant that more cattle survived in the system and milk production was increased compared to a drought year without brush clearing and kalo (S3) (Tables 21 and 32). There was a milk surplus from April to August that generated a small amount of revenue (Table 34) because cattle had enough grass to survive.

The difference in the objective function between S9 and S11 came about because of reduced cost related to land clearing land (higher costs in S9 than in S11). Kalos provided grass more efficiently than land clearing alone, meaning less land needed to be cleared to get similar improvements in the grass endowments (i.e., grass production was higher in kalos than simply land cleared of brush) (Tables 21 and 32). In S9, there needed to be 18,721 hectares of brush cleared to have enough grass to maintain the herd of cattle at full capacity (16,700 head). For S11, the amount of brush that needed to be cleared was only 12,890 hectares and of that, 2,273 hectares were developed into a kalo. This reduced the total cost of land clearing, while providing the needed grass to sustain the herd. As a result, it was basically more efficient to have kalo(s) than just clearing brush alone.

The cattle herd was able to be sustained at full capacity throughout the year but small ruminants were again not selected by the LP model. This again indicated the preference for large animals because they generated more income than small ruminants. The number of camels in the system was reduced from a normal year (S3 and S7) but, interestingly enough, not as much as in S9 where only brush clearing was allowed. This was because there was less total land cleared for S11 than S9 leaving more browse available for camels because the more land clearing and kalo development that takes place, the less browse there is.

The results for S11 indicated that when at full capacity and there was a single drought event, livestock numbers could be maintained in a drought year by clearing brush and, more efficiently, by developing kalo(s). There was still a need for food aid in the community for S11, but the system would rebound better and faster in the year following a drought if brush was cleared and/or kalos developed because the bulk of the livestock, particularly cattle, were able to survive better as a result. The results also indicated that less brush needed to be cleared if kalos were developed.

Scenario 12

S12 allowed excess labor to be used to clear brush and develop kalo(s) at the same costs as described in S11 (Table 13). As was the case in scenario S9 and S10, rather than requiring the model to impute the full cost of clearing brush and/or kalo development in a drought year, this scenario assumed that brush had been cleared in non-drought years and that kalos had also been previously developed. Because the costs incurred in previously clearing land and developing kalos were sunk, this scenario considered only the out-of-pocket costs and labor requirements to maintain the cleared land and kalos to be free of new brush encroachment.

For this scenario, the LP model essentially selected how much land would need to have been previously cleared of brush and/or developed into kalos to maintain livestock numbers at current capacity. This was done to test how existing land that had been previously cleared of brush and/or developing into kalos could sustain livestock numbers during a drought. By so doing, S12 determined how resilient the system would be in a drought if brush were cleared and/or kalos developed and livestock numbers were at their current capacity (Table 14). Because of the drought in 2011, livestock numbers in the study area are currently below full capacity and the community is in a re-building phase in terms of its livestock numbers (Table 13). It was expected that less land would be needed to be cleared and kalo(s) developed than in S11 simply because fewer livestock would need to be supported through a drought at current levels compared to full capacity (S11). Consequently, S12 was a more conservative (less expensive) brush clearing strategy than S11 and could be viewed as method to preserve the system at a level short of collapse but not at full capacity.

Overall income (objective function) showed a deficit of 33,001 Birr per household (about $1,650 USD) (Table 19). There was no crop revenue for S12 because there was no crop harvested due to drought. The amount of land that was cleared and developed into kalo provided enough grass to have a milk surplus in April and May and greatly reduced the deficit in June, July and in August (Table 34). This suggested that brush clearing and kalo development were able to keep livestock alive and to increase milk production in dry years well above what occurs in S4 when a dry year was experienced and brush clearing and kalo development were not allowed. Livestock numbers are unchanged in S12 from S10.

The LP indicated that 2,744 hectares of land needed to be cleared and of that 1,217 hectares were developed into kalo for S12 (Table 35). This is about 5 percent of the total land area of Harweyu cleared of brush and about 2 percent of the land developed into a kalo. This comes at a household cost of 1,718 Birr for brush clearing and 953 Birr for kalo development (Table 19) for a total land development cost of 2,671 Birr per household. This was the major difference between S12 and S10; kalo were more efficient in providing grass than clearing brush alone and, as a result, household costs go down compared to S4 if kalos were developed over simply clearing brush.

The results of this scenario showed that in a restocking year, brush clearing and/or kalo development would have huge impacts in preventing further reductions in cattle numbers if another drought occurred shortly after a previous drought. However, by developing kalo(s), less land needed to be cleared than in S10 resulting in a reduced overall cost for land clearing. There was still a need for food aid, as in the other drought scenarios, but long-term food aid would be less because herd rebuilding would take place faster in this scenario (S12) than if no brush clearing and/or kalo development took place (i.e., S4 and S10). The system would not be set back in terms of livestock losses by as much as in S4. As a result, the community would be in better economic shape than if no land modification took place. This implied that kalo development has the same results as brush clearing only at a reduced cost compared to land clearing alone.

Forage Demand and Species Selection Under the Different Scenarios.

Tables 22-33 reported the demand for forage by forage type and livestock species for each of the scenarios. The results reported in these tables along with those reported in Table 20 revealed how forage availability impacts the choice of livestock species and the number of livestock the system can maintain.

During normal rainfall years (S1, S2, S5, S6, S7, and S8), grass production was sufficient to support the number of cattle specified by the upper bound on livestock numbers in the LP. For example, 16,700 cattle was set as an upper bound for S1, S5, and S7 and that is the number of cattle selected by the LP for those three scenarios (Table 20). For normal rainfall years when the current number of cattle (8,700) was set as the upper bound on cattle (S2, S6, and S8), that is the number of cattle the LP selected (Table 20). During normal rainfall years (S1, S2, S5, S6, S7, and S8), grass was available to support other livestock species requiring grass as part of their diet (sheep and goats).

During dry years (S3, S4, S9, S10, S11, and S12) the LP indicated that no sheep or goats should be produced. The number of cattle in S3 and S4 was well below the upper bound for cattle indicating that grass was a limiting factor for cattle in those scenarios (Tables 20, 24, and 25). This suggested that whatever grass was available during dry years went almost exclusively to support cattle with a relatively small amount of grass going to support camels (Tables 19, 24, 25, 30, 31, and 32). In other words, sheep and goats were "crowded out" of the LP model during dry years by cattle and camels. Cattle were found to be the preferred species of livestock in the Borana Plateau system. The reasons for this were clear when one considered that milk and livestock sales for cattle were the most profitable of all of the livestock. For these reasons and because cattle eat grass almost exclusively, the LP model favored producing as many cattle as possible with any remaining grass once the upper bound on cattle numbers was met being used by goats and sheep. However, goats and sheep were clearly residual claimants of the grass only after the grass necessary to support the maximum number of cattle has been used for that purpose.

Given this result, one could ask why the Boran pastoralists keep sheep and goats at all. Discussions with experts in the Borana Plateau (Tezera 2014) indicated that sheep and goats were kept as a more liquid asset than cattle. This meant that if a household needed a relatively small amount of cash, it was easier to sell a less valuable sheep or goat than to sell one of the cattle. Sheep were also indicated to be kept for ceremonial purposes and also as a hedge against diseases, which seem to affect goats more easily than they do sheep.

Camels used a relatively small amount of grass compared to the other livestock species. Camels utilized brows primarily. They also produced more milk than sheep or goats and had a higher value when they are sold than sheep or goats. For this reason, during dry years camels were selected over sheep and goats to graze on available browse (S3 and S4). Camels also had income from milk and animal sales that was high enough that the LP was willing to allow a small portion of the available grass to be used for camels rather than exclusively for cattle (compare livestock numbers for S1 vs. S3 and S2 vs. S4 in Table 20). In short, camels appeared to be favored especially during dry years over sheep and goats. This matched *a priori* expectations about the reasons that the number of camels in the Borana Plateau had been expanding.

For normal rainfall years, the LP selected the maximum number of cattle specified by the upper bound on cattle (S1, S2, S5, S6, S6, and S8) (see Table 20). This indicated that, at least for the number of cattle allowed in this analysis, that brush clearing and kalo development were not a critical need to maintain livestock numbers either and current levels or at full capacity. However, during normal rainfall years the number of livestock could be expanded through the use of brush clearing and/or kalo development. For example, while not reported directly here cattle numbers well over 20,000 could be supported if brush clearing activities and/or kalo development had occurred before a normal rainfall year. Essentially under normal rainfall conditions brush clearing, and kalo development would be able to support a significant expansion in livestock numbers in the Borana Plateau.

The value of brush clearing and/or kalo development when dry years were experienced was clearly illustrated in S9, S10, S11, and S12. These were the scenarios, which provided for the availability of areas cleared of brush and/or developing kalos prior to a dry year. For these scenarios, cattle numbers could have been supported at capacity (S9 and S11) even in drought years. The extra grass made available by these activities (brush clearing and/or kalo development) would have been used to hold cattle numbers at high levels. The LP results for S9-S12 appeared to suggest that massive cattle die-offs during droughts could be avoided, at least for one year of drought, if brush clearing and/or kalo development had taken place at a sufficient level prior to the drought. This was an important result because it indicated that the pastoralists living on the Borana Plateau would move towards becoming more resilient in the face of drought if more brush were cleared and/or kalos developed.

Synthesis of Scenarios

The results illustrated the system in the study area can be self-sustaining, whether at full capacity or in the current rebuilding year, so long as there was normal rainfall. The revenue coming from livestock sales and milk sales (the amount they do not spend on buying maize) were enough to cover operating expenses and provide an end of the year profit.

The results demonstrated clearly the vulnerability of the pastoralist way of life in the Borana Plateau. The different scenarios showed that with just a single drought year, if previous measures have not been taken, the system collapses and is almost solely dependent on some form of food aid to meet the nutritional requirements of the community. Similarly, the loss of livestock from the system was abundant during drought year scenarios (S3 and S4). If the frequency of droughts increased due to climate change effects, it would be very difficult for the Boran to increase herd size to a sufficient level to meet the energy needs of the human population and to cover operating expenses.

The cropping that was going on in Harweyu, although only on 100 hectares of land, provided enough of a harvest in normal years to reduce the amount of maize that needed to be purchased for the year. In normal rainfall years cropping was a worthy endeavor because household costs to crop were relatively low while a significant amount of food was produced by the crops (Table 18). However, when drought occurred there was a complete devastation of the crop and no harvest occurred. When a drought was experienced, the cost of planting and land maintenance was incurred even though no crops were harvested. The land delegated for cropping was likely the most fertile land and closest to the community's population.

The results showed that the influx of camels into the region had been a good risk management strategy. During dry years there was a milk deficit during each month. Camels provided more milk in dry months and were more tolerant to drought than cattle because their diet consisted of browse that was less impacted by drought than was grass. The LP preferred large animals to small ruminants because large animals (cattle and camels) provided relatively more milk and revenue for the forage required than the small ruminants. Camels also helped fill some of the milk deficit that occurred during a drought.

The results illustrated that the system was affected largely by the number of cattle that were in it. This stood to reason because the Boran are traditionally cattle people. The sustainability of the system during and following dry years depended on the number of cattle that survived during droughts. Cattle were impacted by the amount of grass that was available or was not available. During normal rainfall years, there was enough grass to maintain the number of cattle at their maximum capacity of 16,700. During normal rainfall years, if the herd was at the restocking levels of S2, there was enough grass to allow the herd size to grow. When droughts occurred, the loss of forage in the system, particularly the loss of grass, had devastating results on the number of cattle that could be supported in the system. However by clearing brush and developing kalos, more grass was available even when grass production is reduced on all of the land because of drought. The grass demanded by cattle in S9-S12 (Table 30-33) showed how much increased grass production occurred when clearing land and developing kalos was undertaken to a large enough degree to maintain the herd size (Table 35).

By increasing the amount of grass in Harweyu during dry years (through brush clearing and/or kalo development), more cattle would survive and the Boran would be better able to ride out the dry times. Brush clearing and/or kalo development provided a way to build up a store of grass as a hedge for when a drought occurred. The system was better able to withstand drought years, whether at full capacity or in a rebuilding phase, when brush was cleared and/or kalos developed. Milk production also increased with brush clearing and kalo development as there were more cattle that survived the drought conditions.

The results showed that there was a milk deficit during the LDS in every scenario. But during normal rainfall years, whether the system was at full capacity or in a rebuilding year, there was enough revenue and milk surplus to offset the cost of purchasing food. In a sense, this showed that food aid would not be needed because there was enough revenue to buy the food needed to make up deficiencies. During drought years there was a milk deficit in all months of the year with no revenue to make up the amount needed to purchase milk. These dry-year scenarios showed how dependent the community would be on food aid to meet human nutritional requirements during droughts. However, when brush clearing and kalo activities took place, milk production increased enough that there was a surplus in some months and a greatly reduced deficit in other months (Table 34). There is still going to be a need for food aid during dry years, but brush clearing and/or kalos decreased the amount of food aid needed as well as reduced the rebound time needed to rebuild livestock numbers to full capacity after losses were experienced as a result of drought.

CHAPTER 5

CONCLUSIONS

Ethiopia is one of the poorest countries in the world (USAID 2014) and suffers from a high level of food insecurity. The Borana Plateau is a region in Ethiopia where the pastoralist system and way of life have been greatly impacted by over grazing and a rise in population. Climate change has increased the threat to the pastoralist system as the increased frequency and severity of drought puts the survivability of the system into jeopardy. Drought has devastating impacts on the livestock of the Borana Plateau because massive livestock losses can occur during drought. When these losses occur, the Boran pastoralists lose a main store of their wealth and also the main source of nutrition for the community.

The Boran economy centers on cattle and livestock production. There are not many off farm jobs in the Borana Plateau and raising livestock provides the livelihood, which makes it possible to obtain the major components of their diets. When there are livestock losses and milk production declines during drought, the Boran supplement their diets with cereals (maize). When cereal prices rise faster than livestock prices, even in good times, the poor have difficulty covering the necessary expenses to protect their livelihood. When nutritional deficits occur, food aid is used to ensure that people can survive.

Harweyu was chosen as the study area because of available data. Harweyu also provided a good representation of a pastoralist system with much of its land being overrun with brush and because there is limited cropping activity in the community. Data were collected in the field as well as from previous work and participatory rural appraisals (PRA). Professionals familiar with the study area refined the data used to create the most realistic available information for the values assigned to the parameters that were used in the enterprise budgets and the LP. A "typical" household was developed to show, not only how the community at large fares, but also how households in the community were impacted by any possible development intervention.

It was recognized that there were relationships between agronomics, financial decisions, and nutritional requirements that needed to be considered when analyzing possible interventions in the Borana Plateau. A LP model was used to show the relationships between these different aspects of the system and how they would change as a result of different scenarios (interventions). The LP required that a minimum nutritional requirement for the community be met while at the same time maximizing returns to livestock and cropping activities. The LP was also used as a dial or yardstick to determine the likelihood that different interventions might be sustainable and, consequently, likely to be adopted by the community in the long term.

There were a total of 12 scenarios examined by the LP. The first scenarios established a baseline for how sustainable the community was under current rangeland conditions for different stocking rates during normal rainfall years. Scenarios were also considered which mimicked drought years and were used to determine the resiliency of households and livestock numbers during droughts. Lastly, scenarios simulating possible interventions/strategies related to brush clearing and/or kalo development were tested to determine what impact these activities would have on maintaining livestock numbers enhancing livelihoods in the study area; especially during periods of drought.

The lessons learned from the research results were that the pastoralist system in Harweyu during normal rainfall years was sustainable. The revenue that was generated from various enterprises was enough to purchase milk and maize during months when there was a deficit if it was a normal rainfall year. This was true whether livestock numbers were at current levels (rebuilding phase) or at full capacity (Tables 14 and 20). There was enough revenue generated during normal rainfall years to send some household members to school and to cover annual medical expenses.

Drought has a devastating impact on livestock survival and the projected survival of the system. Cattle were found to be the most important species in Harweyu and their diet depended on grass, which was the most negatively impacted forage when a drought occurred. Camels served as a good defensive strategy to mitigate the loss of milk from cattle during a drought, but there was not enough browse available to support the numbers of camels needed to make up for cattle. Although camels helped see people through the dry months during droughts, the ultimate sustainability of the system appeared to rest ultimately on grass availability and cattle.

Brush clearing and kalo development provided enough grass to see cattle through a drought but a significant amount of land needed to be cleared. Kalos were more efficient in producing grass, especially for the critical LDS, than was clearing brush alone. More grass was produced per hectare in kalos than in land that was simply cleared of brush. Consequently, less land was required to be cleared of brush if kalos were developed than if they were not. There was no economic incentive to clear land in normal rainfall years but if land had been cleared during the good years and/or kalos developed, the system could better survive a single drought occurrence and avoid the need for restocking.

Limitations

There are many areas of this LP that can be further expanded to show how the community can build resiliency into the pastoral system. One limitation in this study was not allowing the herd size to grow past what was estimated capacity. However, if the Boran can clear land, the capacity of the herd would grow also, as they would be clearing brush to allow for more grass. The possibility of growing the herd is an area that could use further research, as it is another way of building resiliency to drought and would decrease food insecurity.

An additional limitation to the model has to do with small ruminants, namely goats and sheep. The reality is there are small ruminants on the Borana Plateau and within Harweyu. The LP basically maximized the forage that is available, predominantly grass, and wants the best return on the forage available. The value of small ruminant may be because they are more fungible and as such have a certain value that exceeds maximizing a return from the forage. This was not built into the model and further research could expand the issue of small ruminants and their true value on the Borana Plateau.

Recommendations

Camels potentially provided a good defensive strategy for mitigating the impact of the LDS on milk production, but the Boran in Harweyu are traditionally cattle people. Camel husbandry experts could be brought in to teach the skills needed to be efficient at raising camels. The results of the LP showed that by clearing brush and developing kalo(s) more resiliency to drought was built into the system and the perpetual need for food aid was reduced. NGOs could incentivize the people in the region to begin brush-clearing activities by paying for the labor to clear the land during normal rainfall years. As a result, there would be better resistance when a drought occurs.

The current method of brush clearing by hand was time consuming. Possibly by providing chainsaws to clear brush, more land would be cleared in a shorter period of time. Chainsaws were a relatively expensive alternative because of the running costs and higher paid skilled labor needed to operate chainsaws. But, the key was the amount of land that could be cleared and the positive contribution to system resiliency resulting from land clearing and/or kalo development. Additionally, if the Boran can be convinced to not graze areas of land that have been cleared for a time, then enough dry material can appear to use prescribed fire as a cheaper more efficient way of clearing brush.

Prescribed fire was an area identified where further research could be done. The difficulty with prescribed burning being the amount of forage needing to be taken out of the yearly use to allow enough dry material to be available on the ground so that fire can spread along the ground and spread from tree-to-tree and bush-to-bush. Also, kalo management strategies may be able to be developed further. For example, determining who has access to kalos and how to best to preserve the integrity of kalos as forage reserves for the LDS needs to be considered further. The rumors of off-farm labor opportunities such as a charcoal plant coming into the area can be an area of study because this new opportunity might provide people with an income without having to be dependent on livestock survivability for their livelihoods.

In general, the results demonstrate the fragility of the livestock system of the Borana Plateau. Without some type of intervention, the system appeared to be unsustainable if severe droughts continued to occur with more frequency. The results suggested that clearing brush and/or kalo development may be an intervention that was sustainable and increased the resiliency of the system while reducing the need for food aid.

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APPENDIX

Table 36. Estimated Cost and Returns for Haricot Beans per Hectare in Borana Plateau

Item			Unit	Quantity	Price	Amount Wet Year	Amount Dry Year
Revenue							
Beans[a]			Kg	4,000	4.00	16,000.00	-
Residue			Kg	1,125.0	2.00	2,250.00	-
Total Revenue						18,250.00	-
Operating Expenses							
Seed[b]			Kg	4.5	11.00	49.50	49.50
Tools[c]	#/Hectare	Life (Yrs.)					
Plow[d]	0.375	6	#/yr/ha	0.063	250.00	15.63	15.63
Machete	1.25	4	#/yr/ha	0.313	150.00	46.88	46.88
Hoe	1.25	4	#/yr/ha	0.313	75.00	23.44	23.44
Oxen Feed[e]			Kg	90	2.00	180.00	180.00
Total Non-Labor Operating Expenses						315.44	315.44
Returns to Land, Labor &Management						17,934.56	(315.44)
Returns Per Hour of Labor						32.73	(13.28)
Returns Per Day of Labor						261.82	(106.25)
Labor[f]							
Land Prep[g]			Hours	160	4.75	760.00	760.00
1st plowing[h]			Hours	96	4.75	456.00	456.00
2nd plowing/Sowing[i]			Hours	106	4.75	503.50	503.50
Weeding/Hoeing[j]			Hours	74	4.75	351.50	351.50
Harvest[k]			Hours	112	4.75	532.00	
Total Labor Expense						2,603.00	2,071.00
Returns to Land & Management						15,331.56	(2,386.44)

[a]Cost and Returns calculated assuming ten households plant a total of eight hectares. 25% of the area planted is beans (Tezera 2014)
[b]Seed is purchased at 11 Birr per kg approximately every third year (year following a drought). Other years some seed is held over and planted (not purchased). Seeding rate is 15kg per hectare (Tezera 2014). Consequently, average purchased seed expense is calculated as 30% of 15kg.
[c]Tools are depreciated using straight line depreciation. The cost of tools as well as their lifespan is an average based on if they were purchased in Addis Ababa or locally (Tezera 2014).
[d]Depreciation based on three plows owned among the 10 households jointly farming 8 hectares (Tezera 2014).
[e]Calculated by the cost of feeding 6 oxen for fifteen days at 2 Birr a day per bale.
[f]Total daily hours worked per person is eight with six hours dedicated to field work and two hours dedicated to prep and transit (Dr. Coppock and Dr. Bailey 2014). Costs assumed to have an opportunity cost of 4.75 Birr/hour ($2/day * 19(exchange rate)/8 hours).
[g]Land prep includes brush clearing, taking one week per hectare for new land. In the years after the initial clearing, land preparation takes two to three days (Tezera 2014).
[h]First plowing takes a pair of oxen six days to plow one hectare (Tezera 2014).
[i]Broadcast seeded and then plowed a second time to cover the seed (Tezera 2014).
[j]Weeding and hoeing is done after seed is covered, takes three people four days working six hours a day (Tezera 2014).
[k]It takes seven days for two people to harvest one hectare (Tezera 2014).

Table 37. Estimated Cost and Returns for Teff per Hectare in Borana Plateau

Item	#/Hectare	Life (Yrs.)	Unit	Quantity	Price	Amount Wet Year	Amount Dry Year
Revenue							
Teff[a]			Kg	3,000	16.00	48,000.00	-
Residue			Kg	1,125.0	2.25	2,531.25	-
Total Revenue						50,531.25	-
Operating Expenses							
Seed[b]			Kg	4.5	11.00	49.50	49.50
Tools[c]	#/Hectare	Life (Yrs.)					
Plow[d]	0.375	6	#/yr/ha	0.063	250.00	15.63	15.63
Machete	1.25	4	#/yr/ha	0.313	150.00	46.88	46.88
Hoe	1.25	4	#/yr/ha	0.313	75.00	23.44	23.44
Oxen Feed[e]			Kg	90	2.00	180.00	180.00
Total Non-Labor Operating Expenses						315.44	315.44
Returns to Land, Labor &Management						50,215.81	(315.44)
Returns Per Hour of Labor						91.63	(13.28)
Returns Per Day of Labor						733.08	(106.25)
Labor[f]							
Land Prep[g]			Hours	160	4.75	760.00	760.00
1st plowing[h]			Hours	96	4.75	456.00	456.00
2nd plowing/Sowing[i]			Hours	106	4.75	503.50	503.50
Weeding/Hoeing[j]			Hours	74	4.75	351.50	351.50
Harvest[k]			Hours	112	4.75	532.00	
Total Labor Expense						2,603.00	2,071.00
Returns to Land & Management						47,612.81	(2,386.44)

[a]Cost and Returns calculated assuming ten households plant a eight hectares. 15% of the area planted is teff (Tezera 2014)
[b]Seed is purchased at 7 Birr per kg approximately every third year (year following a drought). Other years some seed is held over and planted (not purchased). Seeding rate is 18kg per hectare (Tezera 2014). Consequently, average purchased seed expense is calculated as 30% of 18kg.
[c]Tools are depreciated using straight line depreciation. The cost of tools as well as their lifespan is an average based on if they were purchased in Addis Ababa or locally (Tezera 2014).
[d]Depreciation based on three plows owned among the 10 households jointly farming 8 hectares (Tezera 2014).
[e]Calculated by the cost of feeding 6 oxen for fifteen days at 2 Birr a day per bale.
[f]Total daily hours worked per person is eight with six hours dedicated to field work and two hours dedicated to prep and transit (Dr. Coppock and Dr. Bailey 2014). Costs assumed to have an opportunity cost of 4.75 Birr/hour ($2/day * 19(exchange rate)/8 hours).
[g]Land prep includes brush clearing, taking one week per hectare for new land. In the years after the initial clearing, land preparation takes two to three days (Tezera 2014).
[h]First plowing takes a pair of oxen six days to plow one hectare (Tezera 2014).
[i]Broadcast seeded and then plowed a second time to cover the seed (Tezera 2014).
[j]Weeding and hoeing is done after seed is covered, takes three people four days working six hours a day (Tezera 2014).
[k]It takes seven days for two people to harvest one hectare (Tezera 2014).

Table 38. Cost and Returns for Cattle at Capacity for Harweyu in Birr

	Unit	Quantity	Price[a]	Total	Per Head	Amount/Cow	Drought[b]/Head
Revenue							
Milk Revenue[c]	liters	1,666,350	18.00	29,994,300.00	1,796.07	350.00	763.27
Animal Sales[d]	head	1670	3,500.00	5,845,000.00	350.00	1,227.68	300.00
Total Revenue				35,839,300.00	2,146.07		1,063.27
Operating Expense[e]							
Vaccine	head	16,700	-	-	-		
Treatment	head	16,700	30.00	501,000.00	30.00		
Dietary Supplement	head	16,700	72.00	1,202,400.00	72.00		
Total Non-Labor Operating Expense				1,703,400.00	102.00	102.00	102.00
Returns to Land, Labor and Management				34,135,900.00		2,044.07	
Returns per hour of labor				8,685.98		0.52	
Labor[f]							
Herding	hours	3,650	2.38	2,425,277.86	145.23	182.50	145.23
Tula Wells	hours	280	2.38	186,048.71	11.14	14.00	11.14
Total Labor Expense				2,611,326.57	156.37		156.37
Returns to Land and Management				31,524,573.43	1887.70		804.90

[a]Milk price is a weighted average from all species of livestock (Tezera 2014)
[b]Sales increase to 20% of the herd, typically older males. Price is reduced to 1,500Birr an animal (average) (Tezera 2014).
[c]Milk offtake in a normal year for the herd. During a drought milk offtake drops to 708,145 for the herd per year (Coppock 2014).
[d]Sale of animals represent 10% of the herd in normal rainfall years (Tezera 2014).
[e]Treatment and dietary supplements are set costs as provided by Tezera (2014).
[f]Based on a 10 hour day, wage rate aroud $1 USD a day as to not incur high opportunity cost.

Table 39. Cost and Returns for Camels at Capacity for Harweyu in Birr

Item	Unit	Quantity	Price[a]	Total	Per Head	Amount/Doe	Drought[b]/Head
Revenue							
Milk Revenue[c]	liters	383,148	18.00	6,896,664.00	3,629.82	1,044.00	2,216.08
Animal Sales[d]	head	95	17,500.00	1,662,500.00	875.00	4,529.97	675.00
Total Revenue				8,559,164.00	512.52		2,891.08
Operating Expense[e]							
Vaccine	head	1,900	-	-	-		
Treatment	head	1,900	100.00	190,000.00	100.00		
Dietary Supplement	head	1,900	72.00	136,800.00	72.00		
Total Non-Labor Operating Expense				326,800.00	172.00	172.00	172.00
Returns to Land, Labor and Management				8,232,364.00		4,332.82	
	Returns per hour of labor			2,094.75		1.10	
Labor[f]							
Herding	hours	3,650	2.38	398,675.81	209.83	182.50	209.83
Tula Wells	hours	280	2.38	30,583.35	16.10	14.00	16.10
Total Labor Expense				429,259.16	255.93		225.93
Returns to Land and Management				7,803,104.84	4,106.90		2,493.16

[a]Milk price is a weighted average from all species of livestock (Tezera 2014)
[b]Sales increase to 15% of the herd in a drought (Tezera 2014). Price is reduced to 4,500Birr on average.
[c] [c]Milk offtake in a normal year for the herd. During a drought milk offtake drops to 233,919 for the herd per year (Coppock 2014).
[d]Sale of animals represent 5% of the herd in normal rainfall years (Tezera 2014).
[e]Treatment and dietary supplements are set costs as provided by Tezera (2014).
[f]Based on a 10 hour day, wage rate around $1 USD a day as to not incur high opportunity cost.

Table 40. Cost and Returns for Goats at Capacity for Harweyu in Birr

Item	Unit	Quantity	Price[a]	Total	Per Head	Amount/Doe	Drought[b]/Head
Revenue							
Milk Revenue[c]	liters	135,022	18.00	2,430,396.00	238.27	45.60	178.85
Animal Sales[d]	head	2,040	600.00	1,224,000.00	120.00	413.37	90.00
Total Revenue				3,654,396.00	358.27		268.85
Operating Expense[e]							
Vaccine	head	10,200	-	-	-		
Treatment	head	10,200	30.00	306,000.00	30.00		
Dietary Supplement	head	10,200	72.00	734,400.00	72.00		
Total Non-Labor Operating Expense				1,040,400.00	102.00	102.00	
Returns to Land, Labor and Management				2,613,996.00		256.27	
Returns per hour of labor				665.14		0.07	
Labor[f]							
Herding	hours	3,650	2.38	498,344.77	48.86	182.50	48.86
Tula Wells	hours	280	2.38	38,229.19	3.75	14.00	3.75
Total Labor Expense				536,573.95	52.61		52.61
Returns to Land and Management				2,077,422.05	203.67		114.25

[a]Milk price is a weighted average from all species of livestock (Tezera 2014)
[b]Sales increase to 30% of the herd in a drought (Tezera 2014). Price is reduced to 300Birr on average.
[c]Milk offtake in a normal year for the herd. During a drought milk offtake drops to 101,349 for the herd per year (Coppock 2014).
[d]Sale of animals represent 20% of the herd in normal rainfall years (Tezera 2014).
[e]Treatment and dietary supplements are set costs as provided by Tezera (2014).
[f]Based on a 10 hour day, wage rate around $1 USD a day as to not incur high opportunity cost.

Table 41. Cost and Returns for Sheep at Capacity for Harweyu in Birr

	Unit	Quantity	Price[a]	Total	Per Head	Amount/Ewe	Drought[b]/Head
Revenue							
Milk Revenue[c]	liters	34,518	18.00	621,324.00	86.30	16.50	31.55
Animal Sales[d]	head	1,440	600.00	864,000.00	120.00	413.00	90.00
Total Revenue				1,485,324.00	88.94		121.55
Operating Expense[e]							
Vaccine	head	7,200	-	-	-		
Treatment	head	7,200	30.00	216,000.00	30.00		
Dietary Supplement	head	7,200	72.00	518,400.00	72.00		
Total Non-Labor Operating Expense				734,400.00	102.00	102.00	102.00
Returns to Land, Labor and Management				750,924.00		104.30	
Returns per hour of labor				191.07		0.03	
Labor[f]							
Herding	hours	3,650	2.38	498,344.77	69.21	182.50	69.21
Tula Wells	hours	280	2.38	38,229.19	5.31	14.00	5.31
Total Labor Expense				536,573.95	74.52		74.52
Returns to Land and Management				214,350.05	29.77		-54.98

[a]Milk price is a weighted average from all species of livestock (Tezera 2014)
[b]Sales increase to 30% of the herd in a drought (Tezera 2014). Price is reduced to 300Birr on average.
[c]Milk offtake in a normal year for the herd. During a drought milk offtake drops to 12,620 for the herd per year (Coppock 2014).
[d]Sale of animals represent 20% of the herd in normal rainfall years (Tezera 2014).
[e]Treatment and dietary supplements are set costs as provided by Tezera (2014).
[f]Based on a 10 hour day, wage rate around $1 USD a day as to not incur high opportunity cost.

Table 42. Milk Production[a] by Month in Harweyu for all Livestock Types at Capacity in Liters

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cattle	3.500	3.500	3.500	73.500	73.500	50.167	50.167	50.167	17.500	11.667	3.500	3.500
Camels	50.112	50.112	50.112	57.420	57.420	146.160	146.160	146.160	120.060	80.040	50.112	50.112
Goats	1.149	1.149	1.149	8.436	8.436	5.776	5.776	5.776	2.827	1.885	1.149	1.149
Sheep	0.462	0.462	0.462	5.363	5.363	0.550	0.550	0.550	0.908	0.605	0.462	0.462

[a] Seasonal milk estimated provided by Dr. Coppock (2014). For livestock capacity numbers in Harweyu

Table 43. Sample of Foods Available at Market in Yabelo Ethiopia

Food Type	Price in Birr	Unit Size	Price per 100 g
Maize	9	kg	0.09
Teff	12	kg	0.12
Wheat	10	kg	0.1
Millet	8	kg	0.08
Barley	12	kg	0.12
Sorghum	12	kg	0.12
Sugar	20	kg	0.2
Onions	6	kg	0.06
Potatoes	5	kg	0.05
Beets	10	kg	0.1
Lentils	18	kg	0.18
Oats	18	kg	0.18
Peas	13	kg	0.13
Chili Peppers	12	kg	0.12
Haricot Bean	4	kg	0.04
Cabbage	3	kg	0.03
Carrot	15	kg	0.15
Papaya	5	Piece	1.10231
Pumpkin	20	Piece	0.2
Sweet Potato	7	kg	0.07
Sugar Cane	1	Piece	0.01
Avocado	1	Each	0.01
Bananas	10	kg	0.1
Mango	12	kg	0.12
Pasta	16	kg	0.16
Egg	2.5	1	0.025
Ginger	25	kg	0.25
Salt Human	8	kg	0.08

*Note. Prices gathered in May 2013

Table 44. Summary of Nutritional Content Provided in 100 Grams of All Foodstuffs Observed at Market in Yabelo Ethiopia

Nutrient	Measure	Teff	Sweet Potato	Sugar	Sugarcane	Squash	Ginger	Sorghum
Calories	kcal	355.56	55.97	387	398	31.45	80	339
Calories/Fat	kcal	20	0.82	0	0	2.68	6.75	29.7
Calories/SatFat	kcal	0	0.28	0	0	0.55	1.83	4.11
Fat	g	2.22	0.09	0	0	0.3	0.75	3.3
Cholesterol	mg	0	0	0	0	0	0	0
Sodium	mg	22.22	149.67	1	1.1	0.85	13	6
Potassium	mg	--	288.99	2	--	204.85	415	350
Carbohydrates	g	73.33	12.6	99.98	98.6	7.52	17.77	74.63
Fiber	g	13.33	2.01	0	0	2.38	2	6.3
Sugar	g	0	6.75	99.8	98.6	2.8	1.7	1.2
Protein	g	13.33	1.22	0	0	0.76	1.82	11.3
Vit A-IU	IU	0	11692.23	0	0	4439.55	0	0
Vitamin C	mg	0	11.92	0	0	8.16	5	0
Calcium	mg	177.78	23.12	1	28.4	18.7	16	28
Iron	mg	6	0.42	0.05	6.4	0.37	0.6	4.4
Vitamin D	IU	--	0	0	--	0	0	0
Vitamin E	IU	--	0.64	0	--	0.15	0.39	0.11
Vitamin B1	mg	--	0.07	0	--	0.01	0.02	0.24
Vitamin B2	mg	--	0.06	0.02	--	0.06	0.03	0.14
Vitamin B3	mg	--	0.9	0	--	0.42	0.75	2.93
Vitamin B6	mg	--	0.17	0	--	0.14	0.16	--
Folate	mcg	--	3.65	0	--	17	11	--
Vitamin B12	mcg	--	0	0	--	0	0	0
Phosphate	mg	--	32.85	0	--	16.15	34	287
Magnesium	mg	--	16.43	0	--	11.05	43	--
Zinc	mg	--	0.19	0.01	--	0.19	0.34	--

Table 44 Continued. Summary of Nutritional Content Provided in 100 Grams of All Foodstuffs Observed at Market in Yabelo Ethiopia

Nutrient	Measure	Potatoes	Peas	Pasta	Papaya	Onion	Oats	Millet
Calories	kcal	74.42	30.78	330.12	26.66	35.53	389	378
Calories/Fat	kcal	0.77	1.37	17.21	1.45	1.38	62.1	37.98
Calories/SatFat	kcal	0.2	0.24	2.41	0.45	0.23	10.95	6.51
Fat	g	0.09	0.15	1.91	0.16	0.15	6.9	4.22
Cholesterol	mg	0	0	0	0	0	0	0
Sodium	mg	3.42	1.9	0	4.96	2.42	2	5
Potassium	mg	324.2	92.72	81.22	112.84	134.04	429	195
Carbohydrates	g	17.22	5.49	73.12	6.71	8.2	66.27	72.85
Fiber	g	1.54	1.94	12.58	1.05	1.13	10.6	8.5
Sugar	g	0.74	2.15	--	4.85	3.82	--	1.4
Protein	g	1.6	2.06	6.89	0.29	1.1	16.89	11.02
Vit A-IU	IU	2.57	290.7	149.34	589	1.61	0	0
Vitamin C	mg	11.12	15.2	0	37.76	4.2	0	0
Calcium	mg	4.28	9.5	2.62	12.4	17.76	54	8
Iron	mg	0.27	0.56	0.65	0.15	0.19	4.72	3.01
Vitamin D	IU	0	0	--	0	0	0	0
Vitamin E	IU	0.01	0.07	1.29	0.28	0.02	1.04	0.07
Vitamin B1	mg	0.09	0.1	0.14	0.01	0.03	0.76	0.42
Vitamin B2	mg	0.02	0.05	0.06	0.02	0.02	0.14	0.29
Vitamin B3	mg	1.23	0.79	1.46	0.22	0.13	0.96	4.72
Vitamin B6	mg	0.26	0.06	0.15	0.02	0.1	0.12	0.38
Folate	mcg	8.55	24.7	15.72	22.94	12.11	56	85
Vitamin B12	mcg	0	0	0	0	0	0	0
Phosphate	mg	37.64	41.04	199.12	6.2	28.26	523	285
Magnesium	mg	18.82	12.54	94.32	13.02	8.88	177	114
Zinc	mg	0.26	0.47	1.65	0.05	0.17	3.97	1.68

Table 44 Continued. Summary of Nutritional Content Provided in 100 Grams of All Foodstuffs Observed at Market in Yabelo Ethiopia

Nutrient	Measure	Mango	Egg	Maize Meal	Carrot	Cabbage	Beef	Beans
Calories	kcal	42.6	125.84	362	30.59	18.77	31.68	320.6
Calories/Fat	kcal	2.43	75.32	32.31	1.42	0.44	1.17	12.78
Calories/SatFat	kcal	0.59	24.76	4.54	0.24	0	0.18	1.72
Fat	g	0.27	8.37	3.59	0.16	0.05	0.13	1.42
Cholesterol	mg	0	327.36	0	0	0	0	0
Sodium	mg	0.71	124.96	35	50.69	6.53	55.44	0
Potassium	mg	119.28	121.44	287	205.39	159.94	219.6	890.81
Carbohydrates	g	10.64	0.63	76.89	7.18	4.5	7.17	59.65
Fiber	g	1.12	0	7.3	2.62	1.55	1.44	24.04
Sugar	g	9.52	0.33	0.64	3.02	2.28	5.73	0.85
Protein	g	0.58	11.05	8.12	0.66	1.04	1.21	18.85
Vit A-IU	IU	768.22	475.2	214	14886.84	65.28	25.2	0
Vitamin C	mg	25.84	0	0	3.15	30.6	2.59	2.06
Calcium	mg	7.81	49.28	6	26.22	39.17	11.52	158.01
Iron	mg	0.11	1.54	3.45	0.3	0.14	0.57	5.4
Vitamin D	IU	0	72.16	0	0	0	0	0
Vitamin E	IU	0.95	1.38	0.63	1.34	0.17	0.04	0.03
Vitamin B1	mg	0.02	0.04	0.38	0.06	0.05	0.02	0.54
Vitamin B2	mg	0.03	0.4	0.2	0.04	0.03	0.03	0.15
Vitamin B3	mg	0.47	0.07	3.63	0.56	0.2	0.24	1.49
Vitamin B6	mg	0.08	0.15	0.3	0.13	0.09	0.05	0.32
Folate	mcg	30.53	41.36	25	12.24	24.48	57.6	320.6
Vitamin B12	mcg	0	0.78	0	0	0	0	0
Phosphate	mg	9.94	174.24	241	26.22	26.93	27.36	329.76
Magnesium	mg	7.1	10.56	127	8.74	12.24	16.56	121.37
Zinc	mg	0.06	1.14	1.82	0.17	0.16	0.25	2.36

Table 44 Continued. Summary of Nutritional Content Provided in 100 Grams of All Foodstuffs Observed at Market in Yabelo Ethiopia

Nutrient **Bananas**		**Measure**	**Haricot Beans**	**Barley**
Calories	kcal	335.24	354	56.96
Calories/Fat	kcal	9.88	20.7	1.9
Calories/SatFat	kcal	1.38	4.34	0.65
Fat	g	1.1	2.3	0.21
Cholesterol	mg	0	0	0
Sodium	mg	5.78	12	0.64
Potassium	mg	1066.41	452	229.12
Carbohydrates	g	58.18	73.48	14.62
Fiber	g	22.83	17.3	1.66
Sugar	g	5.2	0.8	7.83
Protein	g	26.07	12.48	0.7
Vit A-IU	IU	23.12	22	40.96
Vitamin C	mg	4.34	0	5.57
Calcium	mg	54.91	33	3.2
Iron	mg	9.62	3.6	0.17
Vitamin D	IU	0	0	0
Vitamin E	IU	0.47	0.85	0.1
Vitamin B1	mg	0.49	0.65	0.02
Vitamin B2	mg	0.21	0.28	0.05
Vitamin B3	mg	3.06	4.6	0.43
Vitamin B6	mg	0.51	0.32	0.23
Folate	mcg	523.09	19	12.8
Vitamin B12	mcg	0	0	0
Phosphate	mg	520.2	264	14.08
Magnesium	mg	104.04	133	17.28
Zinc	mg	3.67	2.77	0.1

Table 45. Cost of Clearing One Hectare of Land by Hand in Harweyu[a]

Activity	Hours	Wage/hour	Maintenance	Cost over 5 years
Brush Clearing	1,250	9.60	10%	5,500
Kalo Development[b]	250	9.60	10%	6,600

[a] Note Time estimates from (Tezera 2014). Wage rate is at $2 USD a day poverty line.
[b] Kalo can only be developed on land already cleared of brush.

Table 46. Cost of Clearing One Hectare of Land With Chainsaws in Harweyu[a]

Activity	Hours	Wage/hour[b]	Cost/hour[c]	Maintenance	Cost over 5 years
Brush Clearing	1,000	12.00	115.00	10%	25,400
Kalo Development	200	12.00	115.00	10%	30,480

[a]Inforamtion about clearing brush was provided by Bob Sturtevant from Colorado Forest Service.
[b]Charged 60 Birr a day for chainsaw operator.
[c]Included fuel at 20 Birr a liter, bar oil and chain wear and tear.