FARM OPTIMIZATION FOR HOUSEHOLDS GROWING OILSEED CROPS IN JIMMA, ETHIOPIA.

Napol D. Gurmesa

Supervisors:

Ir. Jo Wijnands
Agricultural Economics
Research Institute
LEI, The Hague

Ir. Gerard Giesen
Business Economics Group
Wageningen University

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Abstract:

The main objective of this MSc thesis was to develop a farm optimization model for households that grow oilseeds and other crops in Jimma region. Developing a farm model was necessary to address due to lacking economic farm research on this subject in Ethiopia. In doing so, 11 crops (teff, wheat, sorghum, maize, faba beans, field peas, soya bean, nueg, linseed, sunflower and sesame) were included in the model. Along with the crops, the major agronomic (rainfall, land and soil) and socio-economic conditions (labor, food security and financial capital) that affect the farm practice were taken into account. As a goal, the gross farm income from these crops was maximized by the model.

The optimization results were separately assessed for the conventional and best farm practices. Under both farm practices, the cropping plan was more or less the same. Maize had the highest share of land (mostly 50%) under most cropping plan of different farm sizes. Apart from the cereals, that consumed the maximum allowed land in all cases (67%), sesame and to a lesser extent soya beans together utilized most of the land left (mostly more than 25%). Small farm size has proven to have a negative impact on the gross farm incomes due to the prevalence of a minimum acreage land required to meet their food demand.

Land was the most common binding resource. A significant difference between the optimal results of conventional and best farm practices was recognized when the effect of constraints was assessed through sensitivity analysis. Under best farm practices, limiting credit facilities has proven to have a far more negative impact, which resulted in fallow lands and extremely low discretionary incomes. The participation of oilseed crops in the optimal plans was mainly represented by sesame and soya beans. Price rises in soya bean improve the land share of soya bean, but not that of sunflower, nueg and linseed. The model led to a number of new, interesting and relevant research topics. It can also be made more comprehensive by including other factors, which can be a stepping stone for future Ethiopian researches in the area.

Key words: *farm optimization, agronomic constraints, socio-economic constraints, gross farm income, conventional farming, best farm practices, cropping plan, cereals, oilseed crops.*

Preface

The accomplishment of this MSc thesis would not be possible without the valuable contribution of a number of people that have supported me during all these years. I feel that the least I can do is acknowledge and thank them.

My dear supervisors, Ir. Jo Wijnands and Ir. Gerard Giesen, were basically the bed rocks of my thesis. Jo instructed me from day 1 and relentlessly gave me critical methodological and academic insights. Every time we met, I learned something from him and I felt my growth intellectually and professionally throughout the process. Gerard, on the other hand, has been a great controller and care taker of my thesis. Without his support and supervision, my thesis would not meet the necessary thresholds. His rich experience with economic principles and modeling has been instrumental in providing me with critical directions and recommendations on how I should proceed every step of the way.

I would also like to thank Ir. Robert van Loo from Plant Science Group. He has been impressively responsive whenever I wanted his help. Biological and agronomic issues were beyond my scope of knowledge and Robert contributed a great insight in filling the gap. He also taught me how to use GAMS, which was invaluable.

And thanks to my colleague and roommate, Jolinda Lute, who has accompanied me during the academic trips and coffee breaks. Our spontaneous chats and jokes have kept my work interesting and stimulating. Finally, I would like to thank my family (dad, mom and sis), who showed me all the love throughout my life and who are actually the reason why I live.

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1 Introduction

In this chapter, background information on crop agriculture in Ethiopia will be first presented. Then, the research problem, the research objectives and questions will be outlined. Finally, the general methodology used in the thesis will be explained followed by the scope and organization of the thesis.

1.1 Background of the study

Agriculture is the most important sector of the Ethiopian economy in terms of income, employment and Gross Domestic Product (GDP). According to Fitsum et al. (2006), agriculture's contribution to GDP, although showing slight decline over the years, has remained very high. Currently, agriculture employs 80% of the national labour force and accounts for 47% of the GDP (Wijnands et al., 2009).

Crop production, among all agricultural activities, is the major contributor to the GDP. The peasant sector, which produces more than 90 per cent of crop output has simple farming technology, acute shortage of purchased inputs particularly fertilizer, little infrastructure and inefficient marketing systems (Arbrar, 2003). With 85 percent of the population (75 million) living in rural areas under subsistence and semi-subsistence (CSA, 2000), Ethiopia needs to accelerate agricultural growth (Gabre_Madhin and Goggin, 2005; Gabre Madhin, 2001).

The oilseeds sector, which is a subset of crop production, is Ethiopia's fastest-growing agricultural sector, both in terms of its foreign exchange earnings and as a main source of income for over three million Ethiopian farmers. It is the second largest source of foreign exchange earnings after coffee. Study reports indicate that Ethiopia is among the top-five producers of sesame seed, linseed and noug, also called neug or niger seed (Wijnands et al, 2009).

Despite its rising significance, stakeholders are convinced that the oilseed production in Ethiopia hasn't reached its climax. Gelalcha (2009) and Wijnands et al. (2009) asserted that the potential for further growth, both in terms of quantity and quality of oilseed crops, through improved production techniques and productivity factors is considered to be great. In addition, evidences point to a growing export of oilseed from Ethiopia to the rest of the world in general.

Many oilseed crops remain largely unknown to a large proportion of Ethiopian farmers. In the region of Jimma for instance, oilseed crops such as soya beans, sunflower and sesame are being introduced as new crops on an established farm. Noug and linseed are the only two major oilseed crops prominently grown in the region (CSA, 2009). Cereals and pulses are by far more known and grown. Cereals in particular are grown over a significant chunk of Ethiopian farms, signalling a large room for oilseed crops to expand their land share.

In the process of introducing the oilseed crops on the farms of Jimma, the primary farm inputs, land, labor and capital are shared with other crops, mainly cereals and pulses. This means competition among the traditional and new crops. The higher resource competition and the introduction of new crops sparks a need for a comprehensive farm model, which facilitates an understanding of the new farm dynamics.

The new farm dynamics set up a different agronomic and socio-economic environment. This is due to the fact that any crop grown over a farm has to qualify both agronomic (soil fertility, rainfall, altitude, crop rotation) and socio-economic possibilities (land availability, labor, food security). Hence, there is considerable need for a model that involves the new crops to address the new farm dynamics and that handles the stronger resource competition between the crops.

As far as we know, there is no farm optimization research at household level for Ethiopian cases that incorporates these crops. The household models that have been developed so far (Singh, 1987) couldn't give a complete focus on crop production. This study will address this research gap by developing a linear programming farm model that maximizes income from these crops. Linear programming is still one of the most widely used optimization model techniques used in modern business. According to Claassen et al (2007), ever since linear programming was introduced, it has been in wide use.

1.2 Research problem

Although oilseeds are widely regarded as a great business engine for the Ethiopian economy, there are no or limited integrated studies of oilseed crop production at farm level along with cereals and pulses.

The Ethiopian Institute of Agricultural Research (EIAR), which is the major farm research institute in the country, gives little attention to researches on economic farm modeling. The core mandates of EIAR are; supply of improved agricultural technologies, popularization of improved technologies and coordination of the national agricultural researches (EIAR, 2010). Hence, it is safe to conclude that much of the focus goes to technological issues. Tesfaye (2007) outlined the socio-economic research branch of EIAR as only focusing on methods of participatory research and technology transfer, monitoring and evaluation of technology packages with regard to adoption and impact, and contributions to policies. Thus, there is a clear gap of knowledge with regard to farm modeling.

The knowledge gap has prevented policy makers, business managers and other stake holders from making well informed decisions in the past. This bottleneck also had its role in depressing the attempts to improve overall crop yields and gross farm incomes. Having adequate well-presented information will improve the efficiency of rural development projects and programs (Samuel, 2006a). This research addresses the knowledge gap by developing a linear optimization model for the crops could help planners as well as future r**e**searchers.

1.3 Objective of the study

The main objectives of this study are:

1. To develop a farm optimization model that involves both oilseed and other crops grown in Jimma region.
2. To analyze the new farm dynamics created by introducing oilseed crops on an average Jimma farm and assess the effect of different factors on cropping plan and income of the farmers.

The objectives of the thesis are reflected in an attempt of answering the following research questions:

a) What are the key crops, including oilseeds, that can be grown in Jimma region?
b) Do these crops fit the actual farm practice?
c) What are the prominent agronomic and socio-economic restrictions in maximizing the income from these crops?
d) How can these crops and restrictions be modelled in line with the analysis of the major crop information such as labour requirement, expenses, returns, etc?
e) What are the optimum results of the model?
f) How do the various restrictions and variables affect the optimum results and what is the effect of different scenarios?

1.4 Methodology

Chapter 3 reviews the overall methodology in developing the optimization model. In this section, a brief description of the study area is presented followed by the data sources for the model and the method of analysis used to extract results of the model.

1.4.1 Brief description of the study area

This study is about the region of Jimma (see figure 1.1). Jimma is one of the 13 zones in Oromiya region in the southwestern part of Ethiopia. It has about 2.5 million people of which 5.7% are urban dwellers and 94.3% are rural dwellers (CSA, 2007). Jimma is known for its rich coffee. Most of Jimma's landscape is midlands which constitute 67% of the land.

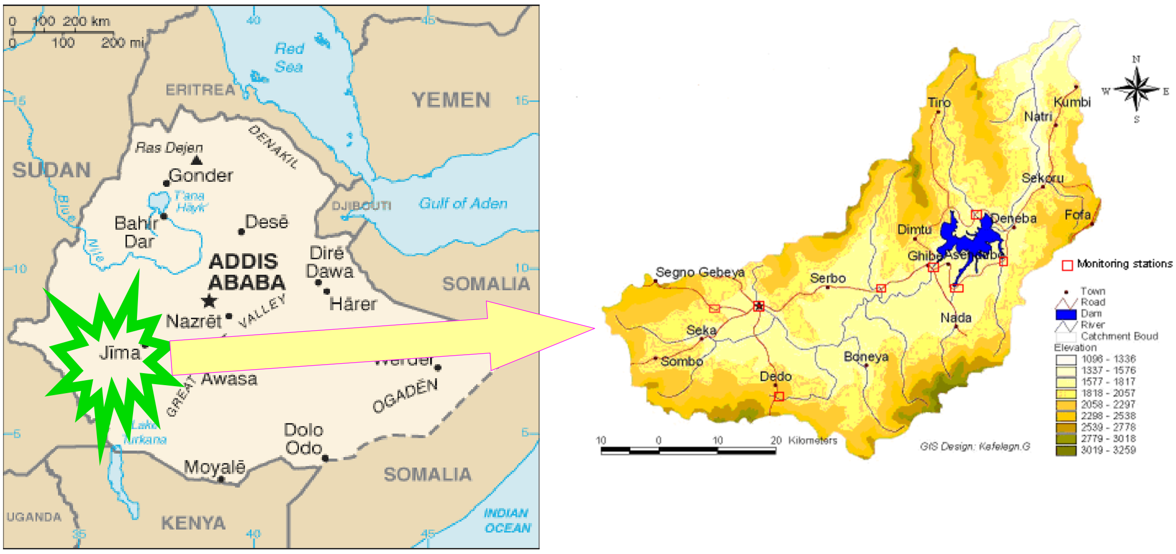

Figure 1 Location of the Study
Source: Jimma University, 2006

1.4.2 Data type and data Source

This research mainly relies on secondary data sources of both quantitative and qualitative nature. The secondary data sources include CSA (Central Statistical Agency of Ethiopia) data, government reports, scientific papers and literature reviews.

The CSA database is used to identify the key crops and oilseeds that are predominantly cultivated in Jimma region. This assists the choice of crops to be included in the model. CSA data also provides the general information such as average yields, rough fertilizer consumption estimates, and other resource requirements. Moreover, literatures depicting the general agronomic and socio economic nature of Ethiopian agriculture are extensively used to identify the major agricultural restrictions. In addition, government reports, Agricultural Association reports are also part of the assessment to cross check facts and solidify findings.

1.4.3 Data collection method

The research is conducted in the Netherlands. So, there is no field assessment and face to face interviews with farmers. Since secondary data is mainly used, much of the data collection is done by reviewing all the sources mentioned above. To fit the data available to the purpose of this research, some restructuring of the available data is carried out.

1.5 Methods of data analysis

In this study, collected data is analyzed using different quantitative and qualitative statistical procedures and methods. Descriptive statistical measures such as means and percentages are used to summarize raw data available about Jimma region. This assists in producing input data or resource consumption data for the crops.

Further data interpretation is assisted by mathematical programming software known as GAMS. Gross farm income data and constraints data will be fed in to the software to perform actual optimization and sensitivity analysis. Hence, the nature of the analysis is mainly quantitative. However, qualitative data will be partly analyzed on spot during data collection to fill the gaps in the quantitative data.

1.6 Scope of the study

This study is a part of an oilseed project in Ethiopia, which is undertaken by the cooperation between LEI and PRI of Wageningen University and Research Centre. The farm model, which is a central theme of this thesis, is specifically developed for the region of Jimma, situated in the Southwest corner of Ethiopia. But the model can serve as a basic framework of analysis for areas with similar social, agronomic and topographic conditions. The main objective of the model is income maximization of farmers. Hence, other possible model objectives such as cost minimization, efficiency promotion and resource optimization are not emphasized as a priority. In addition to this, the model is developed on the themes of linear programming and reflects the possibility of growing 11 crops indicated on a certain farm in the region.

In terms of the variables and constraints taken in to consideration, only a number of socio-economic and agronomic restrictions that have a limiting influence on gross farm income were incorporated. These constraints include land, labor, food security, fertilizer, cash flow and credit limitations. In this regard, the most important constraints critical to the farm conditions of the region were taken in to account. Lastly, the findings from this research can be applied to some areas other than Jimma.

1.7 Outline of the thesis

Chapter 1 is the introduction chapter. Research problems, objectives and methodology followed in carrying out the research are presented. In chapter 2, a brief review of literature on farm optimization models is presented. Chapter 3 provides the basic information on Ethiopian farming. Chapter 4 describes the structure of the farm model and specifies the method used in developing the major parts of the model. This chapter narrows down the general background information discussed about Ethiopian farming in chapter 3 to the region of Jimma and specifies how the model is built for the region along the way. In chapter 5, the main results from the model calculations are presented and explained. Finally, chapter 6 presents the discussions and conclusions of this study.

2 Literature on farm optimization models

In this chapter, two major areas of knowledge pertaining to this research will be briefly addressed. First, the concepts pertinent to farm optimization in general will be briefly discussed. Then a pointed discussion relating the household and farm will be made.

2.1 Farm optimization

Developing farm optimization models is related with planning more than any other conventional management functions. The function of planning in business is covered in various literature and books advocating it as a very critical activity for ensuring business success. The function of planning as a decision making unit in business is well known. To match this notion in farming, Barnard and Nix, (1999) asserted that the farmer is the manager or the entrepreneur of a farm who carries out decision making activities including the function of planning. Planning in business sense is the process of setting organization goals and determines the best strategy in reaching them. In relation to farms, farm models assist how the resources should be allocated enriching more understanding of farms.

Farmers often have little patience with economic principles and tend to dismiss scientific ideas of management functions (Schweigman, 2005). It is true that there are considerable variations and uncertainties between what literature say and what farmers actually face making it difficult to provide neat answers to individual farm situations. Nevertheless, knowledge of these principles is important for better planning and decision making.

The decisions taken in farm planning are not fundamentally different from those that need to be taken in manufacturing or service industry. Barnard and Nix, (1999) pointed out three basic decisions in farm planning:

1. What to produce? That is which activities or a combination of activities an enterprise chooses to carry out. Product-product relationships are usually studied to answer this question.
2. How much to produce? That is at which level of output should be aimed in each enterprise. It relates to factor-output relationship.
3. How to Produce? This answers which combination of resources (alternatively factors or inputs) should be used to produce the products the enterprise selected. The supply of some resources is limited, thus restricting the choice. Here, factor-factor relationships are relevant.

Schweigman (2005) also went on describing the basics of farm planning in terms of crop farming as a combined decision of what, when, how and how much is grown. Most of these questions focused on crops while dealing with farming, which fits the purpose of the thesis. Schweigman (2005) described these decisions in real farm conditions as:

“What is grown depends, among other things, on the character of the soil, availability of water, climate and tradition. When to grow appears in the so called growing-calendar. This gives the points of time on which to start planting or harvesting (growing season). The growing calendar is very much regionally defined. How to grow crops is associated with how often one weeds, how much fertilizer is used, how land is tilled with a hoe or with ox-drawn ploughs, etc. This is mainly where the manual labor is consumed. Lastly, how much must be grown is described by what size of acreage should be for every crop or combination of crops.”

These decisions and farm activities are usually reflected best in farm models. Romero and Rehman (1984) depicted the structure of decision making in farm planning as a linear programming model as:

$$Max.z = f(x) = c'x$$

subject to
$$A x \leq b \text{ and}$$
$$X \geq 0$$

Where
- z the criterion function (usually defined as profit before deducting fixed costs), is a scalar product of _c' and x;.
- x is a vector of decision variables. This might be the number of hectares a crop to be grown, or the quantity of each crop to be produced, etc.
- c ' is the vector giving corresponding contributions of these variables to the criterion function.
- b The vector b represents the physical, institutional and personal restraints that define the environment within choices are made. This refers to the individual economic contribution of each crop to the total economic benefit. It specifies the limits of each restraint. This might be the maximum number of crops in a certain crop rotation, the maximum labor hours available, the timing that must be followed as a result of growing calendar, etc.
- A defines the technical relationships between the variables and the constraints. In other words, it refers to the requirement of a unit of each crop for each restraint. This can be the number of labor hours per crop, the food consumed per each crop, the amount of fertilizer to be utilized for each crop, etc.

Farm level planning usually involves financial objectives such as profit maximization. Other objectives such as peer group standing (Gasson, 1973) and stable level of income (Barnard and Nix, 1999) are also relevant. However, financial objectives are commonly used in farm planning. (Glen ,1986). As indicated, the basic model of farm planning is linear in its core essence. Linearity requires the following assumptions (Bazaraa et al., 1990):

- Proportionality – a change in a variable results in a proportionate change in that variable contribution to the value of the function;
- Additivity – the function value is the sum of the contributions of each term;
- Divisibility – the decision variables can be divided in to non-integer values, taking fractional values. Integer programming techniques can be used if the divisibility assumption does not hold;
- Deterministic – the coefficients are known and constant.

Despite these restrictive assumptions, linear programming models are among the most widely used models today, representing several systems quite satisfactorily and they can provide a large amount of information besides simply a solution

2.2 Farm household model objectives

Optimization of farm activities is usually explained in the background of the relationship between farms activities and households. The typical structure of the flow between households and farms as separate entities can be represented by figure 3.1 below.

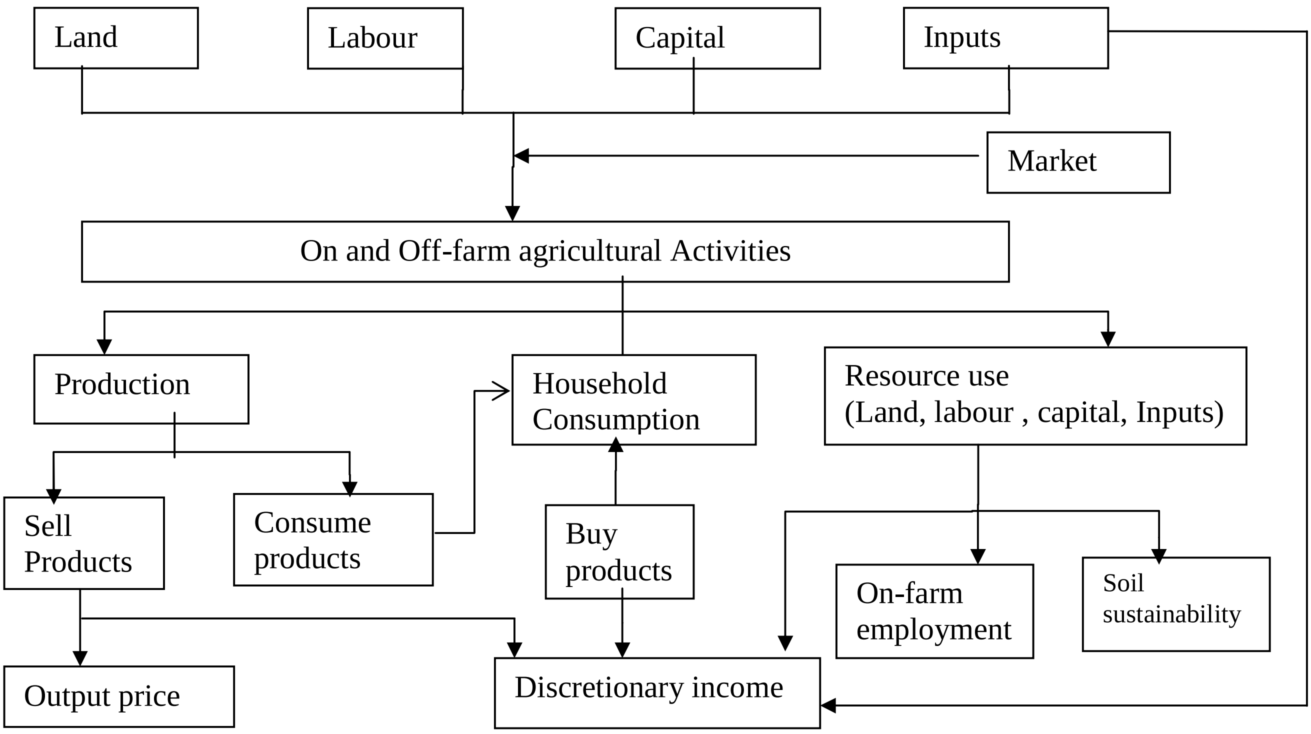

Figure 2 Structure of the farm household model (Source: Castano, 2001)

The figure illustrates the structure of household model, thereby identifying the farm household's restrictions, possibilities and objectives. Farm household restrictions are given by the initial resource endowment. Resources available include land, labor and capital as determined by the appraisal on production cost.

Farm household possibilities are given by on and off-farm production activities. On farm activities are defined for crop and fallow activities, while off-farm production activities refer to off-farm employment possibilities for family laborers.

Production is either destined to the market or used for on-farm consumption. The farm household can buy food and other products that are not produced at the farm. Goods as well as factors can be bought on the market at market prices, while family labor can also be hired out against the prevailing off-farm wage rate.

The household model pursues four objectives: maximum discretionary income, minimum soil erosion, minimum risk and maximum on-farm employment. Discretionary income is defined by Campell and McConnel, (1999) as the "amount of farmer's income available for spending after the essentials (such as production costs, food, clothing, health and shelter) have been taken care of". The result is a part of the disposable income that can be used to finance vacations to retirement or invested or saved fully at the farmer's discretion. In this research, a term closely related to discretionary income called as Gross Farm Income (GFI) is maximized.

There are some differences between gross farm income (the model objective of this research) and discretionary income (as defined in Castano model). Firstly, discretionary income is the residual result of deducting all production costs from farm revenue. However, this model does not take all production costs in to account. Gross farm income excludes fixed costs such as setup cost, acquiring oxen, acquiring the metal equipments. Secondly, costs for clothing, health and shelter are part of the cost deductions under discretionary income. In this research, these items are not part of the deductions. These cost exclusions are the main reasons why the term "gross" in GFI is preferred. It is to indicate that all costs that can be associated with farming are not included.

3 Farming in Ethiopia

This chapter focuses on available information about farming in Ethiopia including the issue of food security to facilitate understanding of farming in Ethiopia for a person who is not familiar to the country. It will present the general farm inputs in Ethiopia and the socio-economic and agronomic conditions.

3.1 General information on farming in Ethiopia

Agriculture currently accounts for about 47 percent of the gross domestic product (GDP), 80 percent of employment, and generates about 90 percent of the export earnings (Wijnands et al., 2009). It also supplies about 70 percent of the raw materials to the manufacturing sector (MEDaC, 1999). Table 1 below reviews the share of Agriculture to GDP by breaking down to crop farming.

Table 1 Share of Agriculture in Ethiopian GDP

Year	*Total GDP in ETB* (billion)*	*Agriculture GDP in ETB (billion)*	*Crop farming GDP in ETB (billion)*	*Agriculture in GDP (%)*	*Crop farming in GDP (%)*
1995/1996	53.6	28.6	17.3	53	32
1996/1997	55.5	28.7	16.7	52	30
1997/1998	53.4	25.2	14.5	47	27
1998/1999	57.4	25.4	15.5	44	27
1999/2000	64.4	28.4	17.7	44	28
2000/2001	65.7	27.7	16.3	42	25
2001/2002	63.5	24.4	13.1	39	21
2002/2003	68.9	26.2	14.9	36	22
2003/2004	91.7	32.2	19.9	39	24
2004/2005	98.4	42.2	27.3	43	28
2005/2006	115.6	50.9	32.2	44	28

Source: FDRE (2006). Note: In 2006 1 US dollar is equivalent to ETB 8.67
*ETB= Ethiopian Birr, currency of Ethiopia.

As it can be seen from the table above, farming has an indisputable place in Ethiopian economy. Agriculture's contribution to the overall GDP in percentage evolved mostly in the high forties. Considering the difficulties of recording in rural areas, the percentage of Agriculture is likely to be higher in real terms.

And within agriculture, crop farming can be regarded as an integral part of Ethiopian agriculture. As indicated, most of Agriculture's contribution to the GDP emanates from crop farming. But within the crop farming itself, there is a big difference with regard to where the focus is. Fitsum etal. (2006) reported that under the dominant farming system in Ethiopia (rain fed system), cereals and pulses alone consume 78% and 16% of the whole land respectively. It is estimated that 8.4 million hectares of land is being used for food grains (cereals, pulses and oilseeds) and other plantations (FDRE 2000).

3.2 The Ethiopian government agricultural policy

At a policy level, Ethiopian farming has gone through various changes in response to different developments. Crop productivity is low and highly unstable. As a result, in recent Ethiopian history, there were two large-scale famines in 1973-74 and 1983-85 caused by consecutive and severe droughts in those years. The 1973-74 famine is estimated to have claimed the lives of roughly 200,000 people (Shephard, 1975).

In response to the famine of 1973-74, the then government launched the policies of land reform and socialist collectivization in an attempt to prevent future famines. This was an attempt to redistribute income and stimulate small-holder agricultural production while discouraging the development of large scale commercial farms. In retrospect, the above-mentioned policies had failed to prevent the recurrence of famines in Ethiopia (Yao 1996). Understandably, a farmer had a little impact to boost productivity and had a little motivation to earn international export and get rich. Therefore, it can be said during the Derg Era, the idea of farm planning is corrupted by the intervention of the Derg regime and the uniformity of policies that should be followed by all the farmers prevented the farmers from being flexible.

In 1991, the government launched the agricultural development strategy where emphasis is put in linking research development through well-focused and targeted transfer of appropriate technology to farmers. The agricultural development strategy aimed at promoting growth, reducing poverty and attaining food self-sufficiency while protecting the environment through safe use of improved technologies (FDRE 2000).

The fundamental transformation of policy in Ethiopian farming came in to being after the fall of the Derg regime. The current government abolished the socialist system of land ownership in 1994 and focused on the commercialization of farms. One of the main policy directions was the encouragement of investments in farming and increase exports. To boost, exports, the Ethiopian government has developed a package of incentives under Regulation NO. 84/2003 to encourage investments in agriculture (Wijnands, etal. 2009).

Within this framework of change, the initiative of farm planning is transferred to individual farmers and to small/medium/large scale companies that own farms. However, the Ethiopian Institute of Agricultural Research (EIAR), which is by far the only significant farm research institution in the country has assisted the farmers with farm planning. EIAR is responsible for the running of federal research centers, and it is administered by the regional state governments. In addition to conducting research at its federal centers, EIAR is charged with the responsibility for providing the overall coordination of agricultural research countrywide, and advising Government on agricultural research policy formulation.

3.3 Inputs of peasant farming in Ethiopia

Peasant farming is the major form of agriculture in Ethiopia. Agricultural production is dominated by the small scale peasant farm sector, which accounts for about 97 percent of farm activities (Addis 2003). The rest 3 percent is commercial farming or large-scale farming, which is growing at an exponential rate. Large-scale farmers tend for a number of reasons to find mechanization more attractive than small scale farmers (Thomas et al., 2009). This could be due to a number of reasons such as financial constraints, lack of technology knowledge and high costs. Mechanization has been encouraged by governments in developing countries through such devices as overvalued exchange rates, liberal tariff policies, and cheap credit. Yet the participation of small scale farmers in mechanization options remains low.

This said, mechanization still has many drawbacks. Not only, the net employment effect of extensive mechanization is generally negative, but the process also uses relatively scarce resources (capital, foreign exchange, skilled labor) to be substituted for relatively abundant ones(labor, traditional skills and implements). Due to the huge capital requirements, most peasant farmers can't afford to utilize modern agricultural inputs like tractors, combine harvester, modern irrigation and so on. These type of tools are usually used in commercial farming. Yao (1996) characterizes the peasant farm production by poor technology, low levels of modern inputs and little irrigation. Due to these circumstances, crop production is greatly affected by weather conditions, especially the amount of rainfall.

Land and labor are the two most determinant farm inputs in the conventional farming of Ethiopia. On average, about 90 per cent of crop output is explained by the two major traditional inputs, land and labor (Yao 1996). Hence, it is easy to imagine that the level of technology dominant in the country. Peasant farming is mainly an ox-driven plough and storage which is supported by metals and shovels for clearing the land and harvesting. Sometimes, horses and donkeys can be used instead of oxen. Farmers can still farm without any animal with a hoe.

3.4 Agronomic conditions

Agronomic conditions refer to the status of natural environment that present a various restrictions on crop yields and gross farm income. Below, are among the most prominent ones with specific customized description for Ethiopia.

3.4.1 Rainfall

While the country is highly dependent on the agricultural sector for income, foreign currency, and food security, the sector is dominated by small-scale farmers who employ largely a rain-fed system. Agricultural yields are highly vulnerable to rainfall variability, perhaps the most important agronomic constraint. Dependency on rainfall is among the major challenges of agriculture in Ethiopia (Reid et al., 2000).

Variability in rainfall has made agriculture an uncertain business especially in arid areas. Because of the unreliable nature and at times also low rainfall and high temperature, arid areas are characterized by shortage of water. Jimma region, which is mostly a mid-land sometimes, shows these characteristics. The good thing is different crops have different rainfall requirements. But by this rain-fed agriculture, the area must give the least requirement of the crops in terms of rainfall.

The income of farmers is responsive to the changes in rainfall levels. Figure 2.2 shows the changes in GDP income with rainfall's deviation from the mean. Importantly, income variability trails rainfall variability.

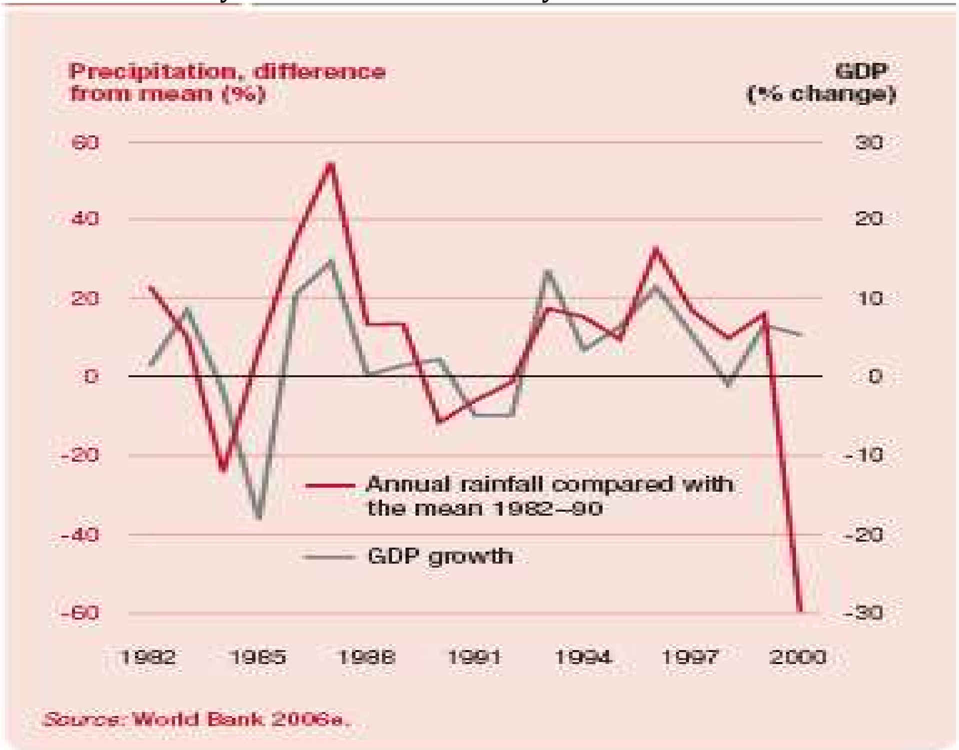

Figure 3 Annual rain variability, Source: The World Bank, 2006.

3.4.2 Land and soil

Land in Ethiopia is a public property that has been administered by the government for more than decades (Samuel 2006). Farmers have open-ended rights to use agricultural land and restricted right to transfer or lease their use right. Thus, land tenure systems under the existing public ownership of land derive from official allocation by local government authorities or through transfer of land use rights.

Smallholder agriculture in Ethiopia is not only facing tenure insecurity problem which the government has been struggling to address recently. But also declining farm size and high farm fragmentation, which again is partly attributed to the existing land policy. Agriculture is predominantly smallholder agriculture where over 85% of farmers operate farms with less than 2 hectare. Such small sizes of farms are fragmented on average into smaller plots. About 11% of farmers were reported to be landless in 2002(EEA, 2002).

Although Ethiopian soil varies from region to region, it is generally considered to be fertile. Two main types of soils are recognized in Ethiopia: the red to reddish-brown clayey loam and the black soil. The former is usually of good fertility but their major deficiency in plant nutrients is phosphorous. The black soils have a tendency to dry out quickly and to crack badly thus hampering the cultivation. Like rainfall, each crop has its own soil requirement in terms of both nutrients and soil acidity. Jimma has largely a soil type known as Nitosols and some areas have soils type known as Vertisols. Nitosols are reddish in color and are derived from complete decomposition of the volcanic lava flows by deep tropical weathering.

3.5 Socio-economic conditions

This section discusses the status of socio-economic conditions that influence the crop yields and gross farm income in Ethiopia. These are labor, food security and capital.

3.5.1 Labor

There are three sources of farm labor in Ethiopia, namely, family labor, hired labor and labor sharing arrangements. A labor sharing arrangement (locally called Dabo) is done between neighbors and between households. Shared labor can be either reciprocal or non-reciprocal. It is reciprocal in the sense that the household has to repay it in the form of labor or in another implicit form. It can be non-reciprocal in the sense that there is no obligation to pay it immediately in the form of labor. Nevertheless, it is usually expected that the household will help the other at times when the other is short in labor. It is common and polite to offer hired and shared-laborers with food and tela (local brewed drink) during work or after the end of the day. Providing laborers with food and tela during work stimulate them to work hard (boost their morale).

3.5.2 Food security

Ethiopia is known for its low level of food security. Its booming population combined with its low agricultural productivity is a recipe for food insecurity. A special focus on food security is given in this thesis since it is expected to influence the basic farm decisions in a farm household model.

In Ethiopia, national food supply management continues to be a major policy concern. The proportion of population unable to attain their minimum nutritional requirements is estimated at 52% of the rural population and 36% of the urban population (MEDaC 1999). What makes agriculture so important in this regard is that 81% of the calorie supply comes from cereals, roots and tubers (Adenew, 2004).

The 1948 Universal Declaration of Human Rights includes the right to food and is formulated as follows (UNCHR, 2010):

> "The right to adequate food is realized when every man, woman and child, alone or in community with others, has physical and economic access at all times to adequate food or means for its procurement."

Worldwide, the consumption exceeds the Dietary Reference Intake (DRI) of energy, proteins and fats. Ethiopians meet the protein reference intake and have a low energy (kcal) intake (See Table 2). The fat intake is almost half the DRI and can be seen as insufficient as it does not meet the UNCHR element adequate. The Dutch consumption is far above the DRI for all categories, which also harms the health.

Table 2 Consumption in 2007 and dietary reference intake of energy, proteins and fats

	Animal	*Vegetal*	*Total*	*Animal*	*Vegetal*	*Total*	*Animal*	*Vegetal*	*Total*
World	481	2315	2796	29.8	47.3	77.1	35.3	44.2	79.5
Ethiopia	96	1884	1980	6.0	50.6	56.7	6.8	14.1	21.0
Netherlands	1058	2220	3278	68.3	36.5	104.7	76.0	60.6	136.6
DRI Male			2400			56.0			50.0
DRI Female			2000			46.0			38.0

Source: Wijnands et al, 2011.

Ethiopian farm families are heavily dependent on home production for their consumption. The staple food of most people is injera and wit. Injera is a porous, sour pancake, a few millimeters thick and 40 to 50 cm in diameter. Although injera made from teff is generally preferred, it is also made from barley, wheat, maize and sorghum or even a mixture of these, depending on availability and price. The ingredients of wot, the highly spiced sauce which accompanies the injera, depend on what is available, fasting requirements and local tastes. Meat wot is preferred, but most farmers can afford it only on feast-days.

The fasting rules of the Christian Orthodox church prohibit the consumption of food containing animal protein (except fish) on Wednesdays and Fridays, and during long fasting periods, such as the eight weeks before Easter and the second and third week of August. Most Christian families are thus confined to a vegetarian diet for 130 to 150 days per year. For those who also observe optional fasting days, the total can be as high as 220 days per year. On fasting days the wot is made of pulses (peas, beans, lentils) and spices.

3.5.3 Credit

Ethiopian farmers incur a range of expenditures on fertilizers, seeds, hiring labor and interest expenses. A sustainable utilization of modern farm inputs (agricultural intensification) is a function of financial incentives to farmers, affordability and availability of farm inputs. Rural financing activities in Ethiopia have mainly concentrated on short-term fertilizer credit and to some extent to pity trade and consumption smoothing purposes, mainly through micro-finance institutions. The government has considered fertilizers as a strategic input to ensure national food security and, consequently, has taken policy measures to ensure its wider use.

The government subsidized fertilizer until 1997 when it abandoned subsidies mainly because of pressure from international institutions. Since then, the government has expended its fertilizer credit substantially to encourage its use and minimize the negative effect of subsidy withdrawal. Demeke (1999) indicates that over 80% of farmers buy fertilizer on credit. But low levels of productivity and land shortage coupled with marketing problems constrain a sustained profitable use of farm credit. Inflexible credit repayment procedures are also widely reported as hindering smallholders' interest in farm credit (Carswell et al, 2000).

Agricultural credit, may be argued, should not only be available to finance short-term farm expenditures but also long-term investment activities cutting across different livelihood domains, both on and off-farm. Smallholders need access to credit for long-term land improvement and capital expenditures that include expenditure for irrigation facilities, farm machinery and post-harvest technologies, as well as to meet short-term seasonal needs.

Private rural-based and small-town business could also be encouraged and supported to engage in the processing of agricultural products and in transport and input-supply operations through providing the required credit for long-term investment and working capital which will also strengthen the efficiency of the smallholder sector. However, medium to long term investment finance is non-existent in most rural areas due to structural problems in the rural sector, including issues related to the land policy like lack of collateral and the smallness of farm sizes.

4 Model description and data interpretation

This chapter describes how the linear programming farm model was developed. It provides the insights behind the elements of the model and interprets some of the data gathered to feed the model. It starts with the general structure giving the overall impression of how model activities and constraints are organized. Then it specifies the major farm conditions and assumptions of the model. Lastly, the chapter dedicates a bulky part to describe the constraints of the model, how they are configured and the framework of the equations used in the model.

4.1 General structure

Table 3 shows the general structure of the linear programming model of this thesis for a 1 hectare farm. It displays the items of both the objective function and the constraints function along with the activities. For easy reference, the activities and constraints are simplified and grouped in Table 3. The real model consists of about 115 constraints and 145 activities. The activities shown in the table are either divided in to crops, periods and other bases. Each option for decomposing each activity and constraint will be discussed in upcoming sections.

As a brief introduction, the columns represent range of activities required to grow and sell crops. The following activities are included in the model:

1. **Buy fertilizers**: this refers to artificial fertilizers that should be bought to facilitate crop growth.
2. **Buy seed:** refers to acquiring a sowing seed needed to start the growth of a crop. Sowing seed can be bought on an external market. It can also be taken from own crop yields of previous farm seasons.
3. **Cultivation:** cultivation activities include the basic farm activities of tilling, sowing, weeding, harvesting, threshing and cleaning. These farm activities can be performed through **traditional cultivation** by the prevailing conventional technology (man-oxen driven technology) or through **mechanized cultivation** by a more sophisticated modern technology (tractor/harvester technology). Mechanized cultivation is a replacement option for the man and oxen hours used under traditional cultivation where a farmer pays a certain amount of money without using any own labor (man and oxen).
4. **Hire man and oxen labor:** labor is hired for the cultivation activities when the labor required exceeds the labor available. This works for both man and oxen labor.
5. **Buy food:** a farmer needs food. He/she can buy a food on an external market to feed his/her family or can reduce from own crop yield in the form of food.
6. **Sell crop:** to generate revenue, a yield of a crop harvested is sold.
7. **Take credit:** a farmer can seek a credit to cover cash expenses. A maximum credit of 1000 birr per hectare is allowed in the model for conventional farming. Under best farm practices, a credit of 200 birr per hectare is allowed. A farmer pays an interest on the credit taken (i).

Table 3 General Structure of the LP model

Activities / Items	Crops per hectare (Crops)	Buy fertilizers (kg) DAP & UREA		Buy Seed (kg) (crops)	Seed from own yield (kg) (crops)	Traditional Cultivation (ha) (Crops)	Hire man labor (hour) (Period 1-26)	Hire oxen labor (hour) (Period 1-26)	Mechanized Cultivation, Replacement option for man and oxen labor under traditional cultivation (ha) (Crops)	Buy Food (kg) (Crops)	Food from own yield (kg) (Crops)	Sell Crop (kg) (crops)	Take Credit (1ETB)	RHS with units
Objective function		DAPp	UREAp	SPc			Wm	Wo	MCa	FPc		Pc	i	Maximize (ETB*)
Constraints (i):														
Land	+1													≤ Available hectares
Rotations	+/- aij													≤/≥ bl-rotation
Fertilizers balance N balance P balance K balance	 +NRc +PRc +KRc	 -Ndap.c -Pdapc -Pdapc	 -Nurea.c -Purea.c -Kurea.c											 ≤ 0 (in kg) ≤ 0 (in kg) ≤ 0 (in kg)
Man Labor (Perd 1-26)						MLt,c	-1							≤ Available man labor in period t (in hours)
Oxen Labor (Perd 1-26)						OLt,c		-1						≤Available oxen labor in period t (in hours)
Cultivation options	+1					-1			-1					≤ 0
Food Requirement	+1									-1	-1			≥ Fc (in kg)
Sowing Seed Requirement	+Sc			-1	-1									≤ 0 (in kg)
Crop Yield Balance	-Yc				+1						+1	+1		≤ 0 (in kg)
Cash flow Working capital Maximum Credit	 -250 -1000	 +DAPp	 +UREAp	 +SPc			 +Wm	 +Wo	 +MCa	 +FPc			 - 1 +1	 ≤ 0 (ETB) ≤ 0 (ETB)

Note: The acronyms used in the table are illustrated in the objective function equation on the following page (page 25) and in the upcoming sections of this chapter.
**ETB= Ethiopian Birr, currency of Ethiopia. Also referred shortly as birr.*

Of all the activities in the model, the activity “Sell crop” produces revenue while others incur costs. The revenue from crop sales minus the costs associated with the required activities is to be maximized. The constraints associated with the activities are presented in the rows of table 3. The constraints are explained in the upcoming sections along with actual data interpretation.

4.2 Explanation of the general structure

Most of the model activities mentioned under section 4.1 are classified per crops. Only labor related activity is classified on the basis of time. The second column is titled as “crops per hectare”. It represents the decision variable for the general model. In section 4.1, the column activities are briefly described. Below, a short description of the rows in table 3 is presented. Mostly, the rows in table 3 represent the constraints.

- **Objective function:** it represents revenue (sell crop or Pc) minus the costs. This is to be maximized. For more details, see section 4.3.
- **Land:** each crop requires a land to be grown. The sum of land used shall not exceed the available hectares. For more details, see section 4.5.1.
- **Rotations:** the crop rotation rules adopted in the model are represented by a host of crop coefficients. For more details, see section 4.5.2.
- **Fertilizer balance:** each crop requires a specific NRc, PRc and KRc amount in kg which is delivered by buying UREA and DAP fertilizers. Each kg of UREA and DAP bought for each crop contain certain amount or proportion of N (Nurea.c & Ndap.c), P (Purea.c and Pdap.c) and K (Kurea.c & Kdap.c). These proportions or amounts of N,P,K in UREA and DAP range between 0 and 1 kg (0% to 100%). For more details, refer to section 4.5.4.
- **Man labor:** traditional cultivation requires MLt,c man hours in period to grow crop C. Man labor can also be hired (-1) in period t. The sum shall be less than the available man hours in period t. For more details about cultivation activities and how they are modeled, refer to section 4.5.3.
- **Oxen labor:** traditional cultivation requires OLt,c oxen hours in period t to grow crop C. Oxen can also be hired (-1) in period t. The sum shall be less than the available oxen hours in period t. For more details about cultivation activities and how they are modeled, refer to section 4.5.3.
- **Cultivation options:** cultivation (farm activities) can be undertaken through the traditional (conventional) technology or through the mechanized technology. Under traditional cultivation, man and oxen labor are mainly utilized (MLt,c and OLt,c). But when opting for mechanized cultivation, a farmer incurs a mechanization cost for the farm activities to grow crops (MCa) in replacing the man and oxen labor that could have been used under traditional cultivation. The cultivation activities with mechanization option include soil tillage, sowing-weeding, harvesting, threshing and cleaning. For more details, refer to section 4.5.3.
- **Food requirement:** the food required in the form of the crops (+Fc) in kg can be delivered by buying (-1) or by taking from own yield (-1). For more details, refer to section 4.5.5.

- **Sowing seed requirement**: the sowing seed required to seed the crops (+Sc) in kg can be delivered by buying (-1) or by taking from own yield (-1). For more details, refer to section 4.5.4.
- **Crop yield balance:** Delivered crop yields (-Yc) shall exceed the sum of the seed from own yield (+1), the food taken from own yield (+1) and crop sold (+1) in kg. For more details, refer to section 4.5.6.
- **Working capital:** refers to the season end summary of cash inflows (250 birr which is the maximum birr amount allowed as a starting working capital and credit taken (-1)) and cash outflows (buying fertilizers (+DAPp and +UREAp), buying seed (+SPc), buying food (+FPc), hiring man labor (+Wm), hiring oxen labor (+Wo) and using mechanized machineries (+MCa) and interest on credit (+1)). There should be at least a neutral cash balance. Selling crops is another source of cash, but it is not included in the cash summary. This is because crop yield is sold in the following agricultural season. For more details, refer to section 4.5.7.
- **Maximum credit:** represents the maximum of 1,000 birr credit per hectare allowed. Under best farm practices, 2000 birr per hectare was allowed. For more details, refer to section 4.5.7.

4.3 The objective function

This model pursues the goal of maximizing the gross farm income from growing crops. Gross farm income, in this case, is the amount of cash available for a farmer to expend on his/her personal expenditures like clothing, family bills, etc., investments or other expenditures Specifically, the gross farm income to be maximized is modeled as the equation:

$$Z = \sum_{c} YSc * Pc - \sum_{c} DAPc * DAPp - \sum_{c} UREAc * UREAp - \sum_{c} SBc * SPc - \sum_{c} FBc * FPc - \sum_{t} HLt * Wm - \sum_{t} HOt * Wo - \sum_{a,c} MCa * MHc - i$$

Where:

Z	*Gross farm income*
YSc	*Yield sold in kg per hectare from Crop C*
Pc	*Farm gate price of crop C in birr per kg*
DAPc	*Amount of DAP fertilizer applied in kg for crop C*
UREAc	*Amount of UREA fertilizer applied in kg for crop C*
DAPp	*Cost of DAP in birr per kg*
UREAp	*Cost of UREA in birr per kg*
MLt	*Number of own man labor in hours utilized in period t*
OLt	*Number of own oxen labor in hours utilized in period t*
HLt	*Number of man labor hours hired in period t*
Wm	*Wage rate per hour for man labor*
Hot	*Number of oxen labor hours hired in period t*
Wo	*Wage rate per hour for oxen labor*
MCa	*Mechanization cost per hectare for cultivation activity a*
MHc	*Amount of hectares under mechanization for cultivation activity 'a' per crop C*
i	*Amount of interest paid in birr on credit taken*

FBc	*Amount of food bought in kg by a farming family in a season*
FPc	*Cost of food bought in birr per kg*
SBc	*Amount of seed bought in kg for sowing per hectare per crop C*
SPc	*Cost of seed bought in birr per kg*
c	*classification for crops. 'c' extends from 1-11, representing 11 crops in the model*
t	*classification for labor periods. 't' extends from 1-26, representing the two week periods in one agricultural season*
a	*is a classification for cultivation activities required. 'a' represents soil tillage, sowing, weeding, harvesting, threshing and cleaning*.

The definition of gross farm income has already been discussed comprehensively in chapter 2. The decision variable of this model is the size of acreage (Ac) on which the different crops are grown. "Ac" can be directly labeled as area of Crop 'c' in hectares; "c" extends from 1-11 incorporating the 11 crops in the model. Most of the items in the objective function equation have a "c" classification, indicated as crop subscripts. The labor costs have classification "t" because labor is distributed on a time basis. Twenty six periods, each comprising two weeks, are used as a basis for developing labor calendar. Further discussion on the labor periods will be cited more specifically when we consider the labor constraint. Classifying the items by "c" assists in a clear decision making from the final results of the model as far as directly relating the specific costs and revenues to the crops is concerned.

Mechanization cost, which is also a cash expense, is the critical part of the model. It is the sum of costs associated with hiring a more sophisticated level technology for executing the farming activities. Mechanization costs (MCa) were classified based on the range of farm activities required to grow crops since each activity incurs different levels of mechanization costs. The activity classifications ('a') includes soil tillage, sowing, weeding, harvesting, threshing and cleaning. Apart from these, off-farm activities such as buying seed and fertilizers can be labeled as input costs. These costs are mainly incurred out of the pocket of the farmer which is particularly true for fertilizers. Seed costs are out of pocket cost for the farmer. The farmer can save crop yields from previous seasons and use them as a sowing seed.

4.4 The Crops

Table 4 below shows some basic information about the crops in Jimma and Ethiopia as a whole. The crops included in this farm model are chosen based on the significance of area covered in Jimma. This was especially true for cereals and pulses. For oilseeds, another criterion apart from area covered such as the opportunity/potential to grow is used.

Table 4 Area and yield in kg/ha of the main crops in Jimma and Ethiopia (Italic are selected crops)

	Year 2008/2009			
	Jimma		**Ethiopia**	
Crop	Area (*1000)	%	Area (*1000)	%
Cereals	**384**	**87%**	**8, 770**	**78%**
Teff	*134*	*30%*	*2481*	*22%*
Wheat	*30*	*7%*	*1454*	*13%*
Maiz	*117*	*26%*	*1768*	*16%*
Sorghum	*72*	*16%*	*1615*	*14%*
Other cereals	31	7%	1451	13%
Pulses	**40**	**9%**	**1575**	**14%**
Faba Beans	*24*	*5%*	*538*	*5%*
Field Peas	*11*	*2%*	*230*	*2%*
Other pulses	5	1%	807	7%
Oilseeds	**20**	**5%**	**855**	**8%**
Noug	*13*	*3%*	*313*	*3%*
Linseed	*4*	*1%*	*181*	*1%*
Soya beans	*n.a.*	*n.a.*	*6*	*.05%.*
Sunflower	*n.a.*	*n.a.*	*8*	*.07%*
Sesame seed	*n.a.*	*n.a.*	*278*	*2%*
Other Oilseed	3	1%	69	.6%
Total grain crops	**444**	**100%**	**11200**	**100%**
Vegetables, fruits, chat & coffee	***117***	**100%**	***941***	**100%**
Coffee (within veg, fruits, chat)	*72*	68%	*391*	42%

Source: CSA, 2009a, page 43. n.a. information not available

Based on the criterion of area covered in Jimma, the following crops are included in the model.

Cereals: (maize, sorghum, teff and wheat)
Pulses: (faba beans and field peas)
Oilseeds: (Noug, linseed, soya beans, sunflower and sesame seed)

Soybean is widely recognized as an oilseed, but in some reports, it comes under pulses. In this case, it is considered as an oilseed crop. Teff, wheat, maize, sorghum and other cereals covered 87% of the total land area in Jimma. As far as pulses are concerned, fava bean and field pea shares about 9% of the land. Noug and linseed together consume the largest oilseed area in Jimma with a share of about 67% of the land committed to oilseeds. Other oilseeds crops chosen (sesame, soybean, and sunflower) have a negligible share.

Coffee, which covers a good deal of land (72, 254 hectare) is not included in the model. Most coffee is merely collected from forest and it is not as labor intensive as the other crops. Furthermore, coffee is not an instrumental crop in terms of food security. It is highly a commercial crop. Most of the coffee farms are now under cooperatives and are being continuously owned by large scale merchants.

4.5 Constraints- conventional farm practice

Conventional farm practices refer to the traditional farming style that is predominant in Ethiopia. This includes farmers that are not in especial government programs and are not participants of farm experiments being conducted by various agricultural research institutions.

4.5.1 Land constraint

The most obvious constraint on any farm is probably the area of land available. Oromiya region's distribution of agricultural households by holding size in table 5 below assists in determining the size of land that a typical farm possesses. It should be noted here that Jimma is one of the sub regions within Oromiya region. Land statistics is only available for Oromiya region.

Table 5 Distribution of Agricultural households by holding size in hectares

Holding size(Ha)	*No of households*
Under 0.1	273,114
0.1- 0.5	852, 682
0.51- 1.00	1, 078, 299
1.01 – 2.00	1, 438, 956
2.01 – 5.00	1,162, 978
5.01-10.00	141, 092
Over 10	10, 544
Total	4, 957, 655

Source: CSA, 2009a

By applying statistical mean calculation for the frequency data, we can arrive at the average agricultural land size. Using the equation: Mean Xi = ∑ Fi * Mi / ∑Fi, the calculated average size is 1.72 hectares. This can be rounded off as 2 hectares. However, to expand the range of results and to analyze the sensitivities of different farm sizes, the results of various farm sizes will be discussed too. This includes farm sizes of 1, 5, and 10 hectares. In simple form, the land constraint can be put as:

$$\sum_{c} Ac + \text{Fallow} <= \text{Maximum land Available};$$

'Ac' represents area sown in hectares per each crop. Fallow in this case is part of the land available which is not exploited for crop cultivation in a certain season of farming. This land may be reserved for livestock grazing, guarding place and the like.

4.5.2 Rotational constraints

In Ethiopia's traditional farming, there are a lot of cropping patterns that farmers exercise and believed to be good for yield and other purposes. About 74.7% of the crop farmers in Oromiya region reported practicing crop rotation as their main method of improving soil fertility (CSA, 2009c).

Despite of the fact that farmers in Ethiopia practice crop rotation widely, the level of information they have on the subject is limited. As evidenced in table 4, Ethiopian farmers in general are only familiar with crop rotation rules that constitute cereals and pulses. Since a number of oilseeds are included in this model, a new knowledge framework is required. That is why many of the crop rotation rules in the model are adopted from guidelines recommended by plant researches and the conventional practices. For that reason, operational adjustments in applying the results of this model to the farming practices of the peasants will be necessary. In terms of Ethiopian calendar, the figure below overviews the seasonal activities with respect to different crops.

Agricultural activities are highly seasonal in Ethiopia mainly due to the timing of rain. It is highly critical that crops are sown during the rainy season. Accordingly, a cropping calendar, which takes approximately 12 months, is divided roughly in to four (or three) activity seasons: plowing, planting, weeding and harvesting (except that planting and weeding can overlap and be considered one season). The calendar begins usually with plowing and the specific timing in the farm calendar depends on the crops

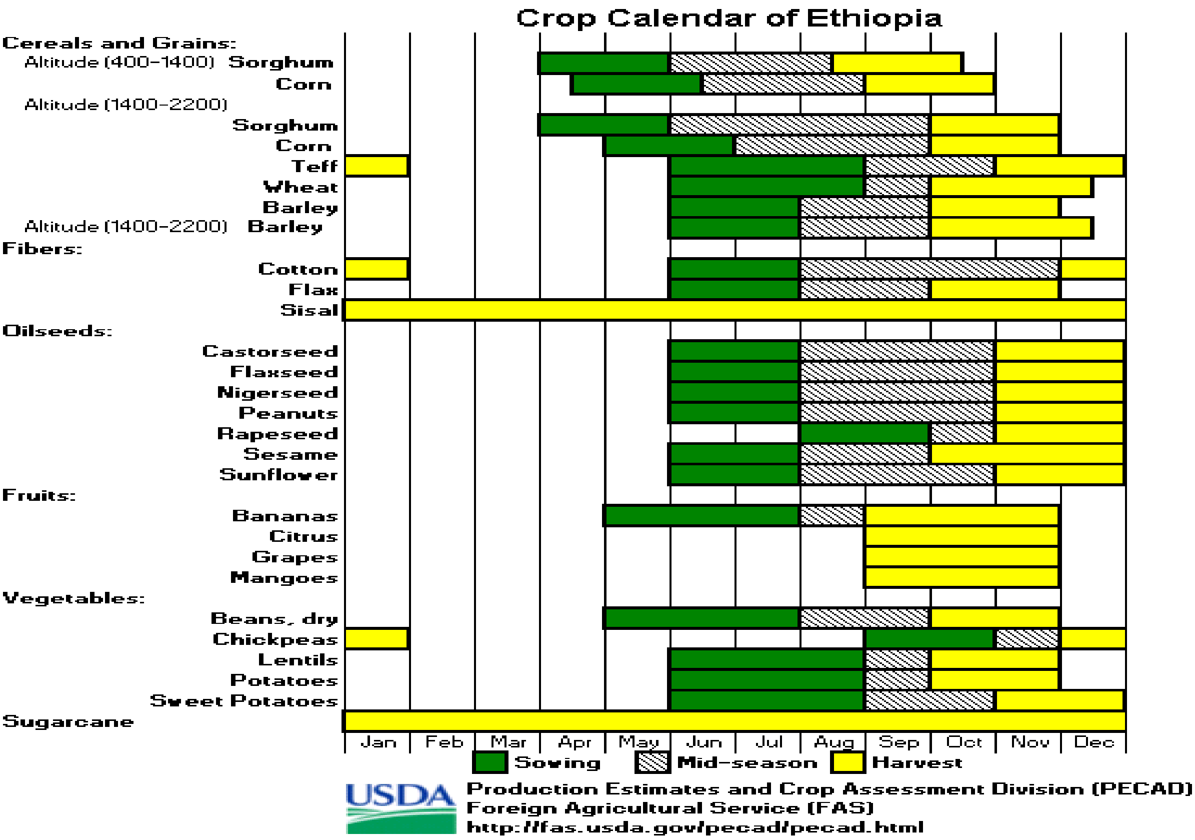

Figure 4 Crop calendar of Ethiopia
Source: USDA

Based on Wijnands et.al. (2011), the following crop rotation rules are adopted in this model.

1. The same cereal can't be grown over two successive years
2. After two different cereals are grown, a non-cereal should be grown
3. Faba beans, field peas and soya beans are grown only once every four years
4. A *Brassica* crop can only be grown once every four years (in the selected set only applies to noug, commonly known as Abyssinian mustard). A Brassica crop includes the likes of rapeseed, canola, black mustard, brown mustard and Asian mustard.
5. Linseed is only grown once in two years
6. Sunflower only once in four years (but no sesame, leguminous or *Brassica* in the four year rotation)
7. Sesame is grown only once in four years.

These rules gave rise to 13 specific crop rotation rules. For their formulation and the corresponding crop coefficients of crops in each rule, see Appendix 5.

These rotational schemes are recommendable rotations that can potentially improve crop yield and prevent soil nutrient losses. But they are rather prudent set of rotation rules meaning the rules may be relaxed in practice, but only after sufficient information has been obtained on practical rotations. For example, in many parts of the world soya bean is rotated alternatively with maize, so perhaps it should be allowed to have soybean once every second year. Sunflower has been shown to perform well after some leguminous crops, so in some USA states crop rotation rules for sunflower have been relaxed. In these cases, practical data from Ethiopian experiences are needed to relax the crop rotation rules.

4.5.3 Labor requirement

Human labor

Traditional Ethiopian farming employs both human and animal labor. For simplicity, all human labor are referred to as manual labor and animal labor are referred as oxen labor in this model. Oromiya region has an average family size of 4.7 which can be rounded to a family with 5 members (CSA, 2005). This will serve as the source of human labor supply. However, not all are economically active. Family members under the age of 18 are considered as full time students and will only be available for labor during school breaks.

By breaking down the age structure based on the national age distribution of the CSA, 3 out of 5 members are considered to be economically active all year around. But one of the 3 members is considered to be not active on the farm, mainly serving as cook and responsible for other miscellaneous family activities, typically the mother of the household.

The labor seasons are broken down on a two weeks basis. This means a single agricultural year will have 26 periods. The labor hours available for all periods are not constant. In accordance with Ethiopian calendar, periods of school break will have more labor available due to labor of the students in the family. These are six periods in a calendar they will work on the farm; July 4 – 17, July 18 -31, August 1-14, Aug 15 – 28, Aug 29 – Sept 11, and Dec 19 – Jan 1. These periods supply 288 hours of manual labor bisected as; 8*6*2*2 + 8*6*2. The first supply (8*6*2*2) represents 192 labor hours from the two economically active members of the family that work all year around on the farm. The description of 8*6*2*2 stands for two economically active family members working 8 hours per day for 6 days for 2 weeks. These 192 hours are the available labor for the remaining 20 periods of the agricultural calendar. The additional available labor hours for the six periods(8*6*2) come from school break of the children who work together in total for 8 hours for 6 days in 2 weeks.

There will be hired human labor when the labor required exceeds the labor supply. This is true especially for rainy months like June and July that are labor intensive as the farmers have to plant the crops during this season of the year. The soil tilling activity is the major agricultural activity during this time for which additional labor is needed. On the other hand, harvest times like the months of October and November also need more labor than other months and thus, need hired labor.

Animal labor
Traditional farming also employs a great deal of animal labor. In Ethiopia, oxen are mainly used for plowing the soil for transporting the harvested crop and threshing. Donkeys are of great use especially to transport items. Transporting by donkeys can occur in both conditions of moving harvested crop to threshing area and moving threshed crop to storage area. Due to the significant use of oxen and other animals, the labor calendar is developed as done for the manual human labor. But due to the different type of animals used in different period, it is proper to divide the activities for farms.

CSA (2009b) indicates renting oxen or pairing with someone else's ox, particularly for tilling purpose, is common due to the increasing problem of oxen shortage. In 2009, 852,687 farmers nationally reported renting an ox while 2,821,080 farmers paired their ox with someone else's. In Jimma region, 33 % of crop holders had no ox, 30% had one ox, and 32% had two oxen. Extra oxen hours may be hired in case of labor deficiency. In this model, it is assumed that a family owns a pair of oxen that work for 8 hours per day for six days providing a constant 192 single oxen hours available in each period.

The model allows the hiring of labor in each period. The hired labor can be used to perform any activity that requires manual intervention by man. Below, the descriptions of essential cultivation activities performed by both man and oxen labor required for growing the crops are given.

4.5.3.1 General Activities
The general activities are the farm activities that lead up to tilling and some activities after cleaning. They are considered as activities that are accessory to the main agricultural activities such as tilling, weeding, harvesting and cleaning. These

activities include manure application, land preparation and some parts of transporting and storage. The activities can be mechanized. But due to their trivial nature, they are mostly executed manually.

Manure application is one of the minor activities in Ethiopian farming, but considered important. Organic fertilizer is still widely used in Ethiopia. In 2009, 32% of peasant holdings used natural fertilizers on cropland areas (CSA 2009c). Animal manure is the major natural fertilizer on use in Ethiopia. However, thrown food and other garbage materials are also applied.

Mostly, manure and other materials are dumped on crop lands right after the harvest of previous season is ended. It is not a labor intensive activity even though it requires some attention in the follow up. In the model, the four periods after the harvest period is ended are dedicated to manure application. In each period, 4 hours is given to manure or other natural fertilizer application. Manual labor by human is the only type of required labor to undertake manure application (See Appendix 1). In traditional context, manure application is not supported by any modern machine or the like.

Land preparation is the farm activity before soil tillage. It is also mainly performed by manual labor without a need for animal labor. After the last harvest, crop lands have the tendency to grow grasses and unwanted plants. It needs labor intervention to remove the unwanted plants. The amount of labor hours given to land preparation is the same for all crops per hectare which is 12 hours (see Appendix 1). Contradictory to this, it is assumed in the model that the land to be used for farming has been cultivated.

Finally, transporting and storage refers to the activities after cleaning a harvested crop. Transporting is related to the human activity required to carry a crop yield from a farm slot to household's location for consumption or market place for sales. The storage is mainly related to the follow up needed to protect any harm to a collected yield. Some crops require extra care to prevent yield from insects and other sources of risk (See Appendix 1). Both transport and storage activities could be less or more labor intensive depending on the amount of the harvest and the care required in keeping a yield safe.

4.5.3.2 Soil Tillage

Soil tillage is considered a major farming activity in Ethiopia. Ethiopians have a peculiar way of plowing farm lands which is quite traditional. Almost all peasant holders make use of a tilling material made from wood. The only metal in the tilling material is the part that goes in to the ground. It is not an expensive proposition to obtain it, but the efficiency of the tilling material is far behind the modern machineries using a tractor. Its inefficiency is mainly related with the huge amount of labor it consumes to cover a considerable amount of farm field.

Different crops have varying need of soil tillage. Some crops respond only to well-tilled soil. For instance teff, wheat and some oil seed crops need more tilling than other crops. In this model, a one-time tilling is equated to 32 hours of manual labor and 64 hours of oxen labor (2 oxen each 32 hours). Tilling is one of the few farm activities that need the intervention of both human and animal labor. Sometimes, half tilling of 16 hours can come in to effect on the sowing day of a crop. This is because half tilling is considered easier and it is on softer soil as it is done within a short time interval after previous tilling. It takes half an effort of completing the same area of land to till. For the number of hours required in each period, see Appendix 1 and Appendix 2.

Even though the conventional way of tilling is made by oxen and human, another option of tilling (tillage by tractor) is taken in to account in the model. The cost of hiring a tractor and machinery or to till is 500 birr per hectare and so skyrocketed compared to the traditional way of tillage. This can assist in assessing the viability of tractor involvement and see if it can be included in the optimal cropping plan. This option is modeled as shown in table 6.

Table 6 Soil tillage

	Area per crop in ha (crops)	Traditional Tillage by Ox (Crops)	*Hire Man labor* (Periods)	*Hire Oxen Hours* (Periods)	*Tillage by tractor mechanization (Crops)*	*RHS*
Man Labor						
Period 1		MLt	-1			<= Available man hours in period 1
.						
.						
Period 26		MLt	-1			<= Available man hours in period 26
Oxen Labor						
Period 1		OLt		-1		<= Available oxen hours in period 1
.						
.						
Period 26		OLt		-1		<= Available oxen hours in period 26
Tillage options	+1	-1			-1	<=0

4.5.3.3 Sowing – weeding

In the model, the sowing activity includes all efforts needed to break down the tilled soil and distribute the seed. Tilling can still be undertaken on sowing day, but it is not included under sowing activity due to its unique nature that requires both oxen and manual labor. The activities mentioned under sowing are mainly done by manual labor. These activities include distributing the seeds on the tilled soil and some hand work to break down the tilled soil to get rid of weeds in the soil. Crops that require softer soil to be planted are more likely to require more sowing hours. In the model, sowing hours of manual labor are awarded on a crop by crop basis.

Nearly all crops in the model require some level of weeding. Weeding mainly facilitates the growth of planted crops. It can be undertaken either traditionally or in a modern way. Expectedly in Ethiopia, the traditional way of weeding is predominant. Traditional weeding is performed by hand which requires only manual labor. On the other hand, modern weeding is undertaken through the intervention of a tractor. However, tractor can only come in play if the seeds are planted in rows. This makes it less likely for Ethiopian case since most farmers use broadcasting of the seeds as a major sowing technique.

The modeling of both sowing and weeding is the same for how the activity of tillage was handled. There will be technology option of sowing and weeding by tractor. However the cost of tractor is different this time. Details of man and oxen labor hours and costs are provided in Appendix 1, 2 and 6.

4.5.3.4 Harvesting, threshing and cleaning

This farm activity incorporates the range of activities from harvesting of a crop to the cleaning of harvested crop, leaving the yield to be stored. It represents a highly critical part of farming in Ethiopia.

After the rainy season is over, the major farming activity of Ethiopia's agriculture is harvesting. In the model, harvesting activity refers to broad range of undertakings involving cutting off or drawing out a crop, preparing the threshing area and transporting the cut crops to the threshing area. The end of the harvesting activity marks when the crops are ready to be threshed or cleaned.

The amount of hours required to do these things are again put on a crop by crop basis (See Appendix 1 and 2). Crops that are tiny and compact in nature tend to require more harvesting hours. The same is true for threshing and cleaning. Small seeds tend to consume more hours of threshing and cleaning. In this regard, crops like teff, sorghum, linseed, wheat and noug will need more labor hours.

Animal labor for threshing may be involved for some crops. However some crops are delicate to be overrun by animal feet. Hence, the manual and oxen labor may be combined for some crops and not for other crops. The modeling of these activities is still consistent as it is portrayed for tilling (See table 6).

4.5.4 Fertilizer and sowing seed requirement and costs

Fertilizer and sowing seed requirements are often regarded as the most direct input costs for farming. However, the inorganic fertilizers can only be bought. Urea and DAP are the two most prominent fertilizers bought and applied. The CSA data are used to derive current fertilizer requirement of N, P and K. Urea and DAP use have been converted to N and P using (0.46 N per kg urea and 0.46 P per kg DAP). K-requirement was calculated from exported K in seed (= seed yield x K-content in seed) and using a recovery of 70 % of K-applied. The specific nutrient amount required for each crop and other details are provided in Appendix 4. The cost of DAP and UREA were directly adopted from the fertilizer market in Ethiopia. DAP costs 2.55 birr per kg while UREA costs 2.5 birr per kg (CSA, 2009c).

As indicated, sowing seed can either be bought on the market or taken from previous yields. The cost of sowing seed on the market is derived from the farm gate prices of each product. It is assumed that the sowing price is higher than the farm gate price. This is due to two reasons. First, the sowing season is usually at the time of low supply of crop yields on the market. Secondly, there will be additional cost of storing added to the farm gate price which is incurred between time of harvest and the season of sowing. Thus, the seed price is assumed 1.5 times the farm gate price and 3 times in the case of best farm practice. Table below shows the farm gate and the sowing seed price of each crop.

Table 7 Farm gate and Seed Price of the crops

Crops	birr/kg Farm gate price	Birr/kg Seed Price (Conventional farming	Birr/kg Seed Price (Best farm practices)
Teff	6.0	9.0	18.0
Wheat	5.0	7.5	15.0
Maize	3.5	5.3	10.5
Sorghum	3.5	5.3	10.5
Faba	4.8	7.2	14.4
Fieldpea	5.3	7.9	15.9
Soya	4.0	6.0	12.0
Noug	5.5	8.3	16.5
Linseed	5.0	7.5	15.0
Sunflower	5.3	7.9	15.9
Sesame	8.0	12.0	24.0

4.5.5 Food requirement

Food security is one of the greatest challenges faced by Ethiopian farmers in general. Historically, the region of Jimma has not encountered a big problem in feeding its people. One of the major purposes of this model is to make sure that there is a condition set that ensures there is at least a minimum food available for the family. The farmer's family uses most of all produced agriculture products for own consumption.

Own produced goods will be the main source for consumptions. Figure 5 shows the share of own use on the average farm. Of the cereals and pulses over 80% is used for either consumption or sowing seeds. Of oilseeds, 65% is used for these purposes. Cereals are the most important food crops, the production amounts 145 million tons, pulses are the second (20 million tons). The quantity of oilseeds (7 million tons) is a mere 5% of the cereal production. Neug, sesame seed, rapeseed, beef and eggs are mainly sold, providing the farmers cash. In conclusion, the major part of the crops is consumed on the own farm.

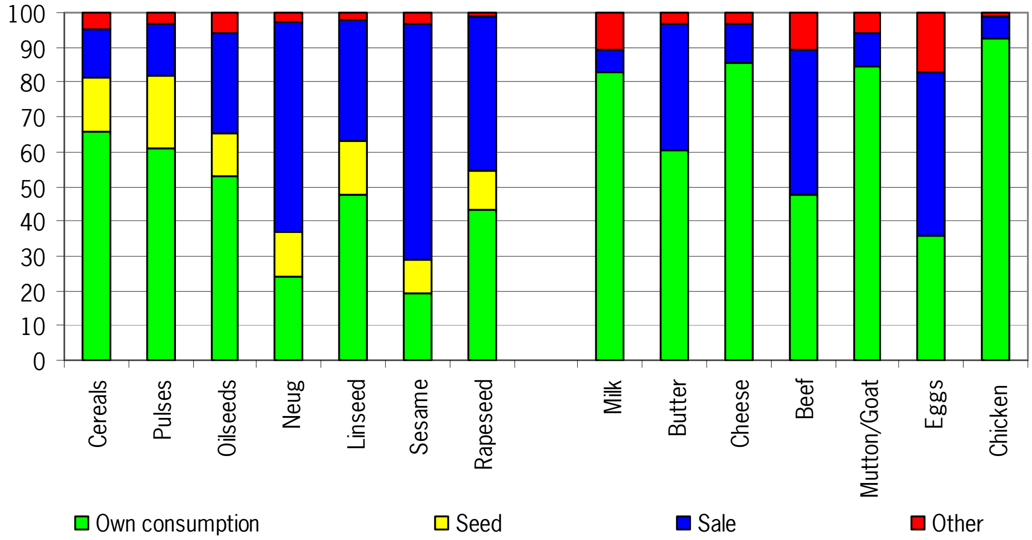

Figure 5 Percentage utilized of production in 2008/2009 (2001 E.C.)
Source: Wijnands et al., 2011.

Based on the above distribution the amount food consumed in kg by a typical family is calculated in a way portrayed in table 8:

Table 8 Food consumption computation

Crops		Produced *1000 (tons/year)	Consumed (%)	Amount consumed (tons/year)	per head consumed (Kg/year)	Family Consumption (Kg/year)
Cereals						
	Teff	1,508	67	101,050	46	230
	wheat	464	58	26,912	12	61
	maize	3,097	75	232,310	105	528
	sorghum	1,230	77	94,731	43	215
Pulses						
	Faba	276	55	15,226	7	35
	Field	109	55	6,008	3	14
	Soya	1	0	0	0	0
Oilseeds						
	Nueg	53	53	2,846	2	10
	linseed	20	32	668	1	5
	sunflower	1	0	0	0	0
	sesame	12	0	0	0	0

The last column in the column above represents the food required per crop for a family to survive (Fc, see table 3). In the model, "FOc" is the amount of food consumed from own yield per year per family. The farmer can still buy food from outside but at a price (FBc) of 1.25X the farm gate price. In essence, this can be put as:

- FOc - FBc >= Fc (See table 3)

4.5.6 Crop yield balance

The yield of each crop goes through various deductions before the final balance is reached. Appendix 3 shows the input requirements that transact within the yield balance. The seed consumption from own yield, food consumption from own yield and amount of yield sold represent the deductions from the crop yields. These deductions shall not exceed the actual yield of a crop. These transactions can be converted in to an equation model that looks like:

-Yc + Soc + SBc + YSc <= 0 (See table 3)

Where:

Yc	*Actual yield in kg per hectare from crop C*
SOc	*Amount of own seed used for sowing with zero cost per crop C*
FOc	*Amount of own food consumed with zero cost per crop C*
YSc	*Amount of yield sold in kg per crop C*

4.5.7 Cash flow requirement

Cash flow is a summary of projected cash inflows and cash outflows for a business over a given period (Ronald et al, 2008). It is desired in this model that a particular farm has at least a neutral cash balance. This requirement, which is explained in the equation below, captures all the cash receipts and cash expenses covered in this model for all the periods that have an impact on the working capital.

Besides, a maximum starting working capital of 250 birr per hectare and a maximum credit of 1000 birr per hectare are allowed. These two provisions are the sources of cash which serve as the first amount of cash a farmer needs before growing the crops. The other cash source is the sales from crop yields. The working capital balance equation in the model can be put as:

$$WC = -SC*FS - C*FS + \sum_{c} DAPc*DAPp + \sum_{c} UREAc*UREAp + \sum_{c} SBc*SPc$$
$$+ \sum_{c} FBc*FPc + \sum_{t} HLt*Wm + \sum_{t} HOt*Wo + \sum_{a,c} MCa*MHc + i <= 0 \quad \text{(see table 3)}$$

Where:

WC	*The working capital balance of a farmer in a season.*
SC	*Starting working capital allowed for a farmer in a season per hectare*
FS	*Available farm size in hectares*
C	*Amount of money borrowed in birr by a farmer in a season per hectare*
YSc	*Yield Sold in kg per crop C*
Pc	*Farm gate price of Crop C in birr per kg*
DAPa	*Amount of DAP fertilizer applied in kg*
UREAa	*Amount of UREA fertilizer applied in kg*
DAPp	*Cost of DAP in birr per kg*

UREAp	*Cost of UREA in birr per kg*
HLt	*Number of manual labor hours hired in period t*
Wm	*Wage rate per hour for manual labor*
Hot	*Number of oxen labor hours hired in period t*
Wo	*Wage rate per hour for oxen labor*
MCa	*Mechanization cost per hectare for cultivation activity a*
MHc	*Amount of hectares under mechanization for a cultivation activity per crop C*
i	*Amount of interest paid in birr on credit taken*
FBc	*Amount of food bought in kg by a farming family in a season*
FPc	*Cost of food bought in birr per kg*
SBc	*Amount of seed bought in kg for sowing per crop C*
SPc	*Cost of seed bought in birr per kg*

4.6 Best farm practices

The second major farm situation considered in this model is the best farm practices. Best farm practices refer to the farmers involved in especial government programs and follow specific scientific recommendations of farm research institutions. This practice usually results in higher yields, but at high costs and resource consumption. (See table 9)

The framework of equations for best farm practices and the conventional farm practices are the same. However, the coefficients may differ. Table below summarizes the differences from the conventional farming.

Table 9 Major differences between the two farm practices.

Item	Best farm practice	Conventional farm practices
Seed	Improved seed varieties are sown under best farm practices. The seeds can only be purchased from a special seed market at an expensive rate. In this model, the seed price is assumed 3X the normal farm gate value of the crops.	Purchase of seed at 1.5X farm gate value is allowed or seed is taken from own yield.
Human Labor	The number of human hours needed under best farm practice is greater due to extra human intervention needed. Extra labor hours are required for three reasons. First, an extra tillage is required in best farm practices as the soil has to be softer. Second, higher yields mean greater number of harvest, threshing and storage hours. Third, extra care and supervision of crops is required under the best farm practices.	Human labor hours are calculated for different farm activities based on the specific crop requirement for each activity.
Oxen Labor	Oxen labor hours will also be greater. An extra soil tillage and threshing under best farm practices means more oxen hours.	Oxen labor hours are calculated in the same way for human labor hours
Fertilizer	Specific scientific recommendations of fertilizer to achieve maximum yields under the circumstances are adopted.	The fertilizer consumption is based on the CSA data.
Credit	A credit of 2000 birr per hectare is allowed. The amount allowed is higher than under the conventional practices because of the fact that more cash expenses are required. Fertilizer and seed cost is by far greater under the best farm practices.	A credit of 1000 birr per hectare is allowed under the conventional farming.
Yield	Special program yields adopted from farm research institutes. These yield figures are typically higher than the yields of conventional farming.	Actual yields recorded based on CSA data
Crop protection expense	Crop protection expense exists under best farm practices. It is a unique cost incurred to give extra care and follow up for the growing crops.	Crop protection expense does not exist under conventional farming.

4.7 Summary information of crops

The two tables below summarize the prominent input information for the crops in the model. The nominal gross margin before optimization is computed for each crop. It is calculated as:

GMc = Yc*Pc – DAPc*DAPp – UREAc*UREAp – Sc*(Pc*k)

Where

GMc	*Gross margin per hectare of crop C*
Yc	*Actual yield per hectare in kg from crop C*
Pc	*Farm gate price of Crop C in birr per kg*
DAPa	*Amount of DAP fertilizer applied in kg per hectare*
UREAa	*Amount of UREA fertilizer applied in kg per hectare*
DAPp	*Cost of DAP in birr per kg*
UREAp	*Cost of UREA in birr per kg*
Sc	*Amount of seed required per hectare to grow crop C*
k	*Cost multiplier for seed cost. As discussed, 'k' is 1.5X the farm gate price for conventional farming and 3X for best farm practices.*

In short, the gross margin is estimated as sales from a crop yield minus the fertilizer and seed costs. Fertilizer and seed as discussed above are the major input costs for which a farmer expends cash by buying items from an external market. It gives some indications on how a given crop is financially attractive.

Table 10 Crop summary under conventional farm practices

Crops	Gross margin Birr/ha	Man'l labor Hrs/ha	Oxen labor Hrs/ha	Actual Yield Kgs/ha	Farm price Birr/kg	DAPc Kg/ha	UREAc Kg/ha	Seed rate Kg/ha
teff	5473	556	506	1000	6	60	120	30
wheat	5532	496	360	1400	5	72.5	145	175
maize	6506	324	200	2000	3.5	85	170	15
sorghum	4596	396	272	1500	3.5	25	50	120
faba	3438	380	184	1000	4.8	50	100	185
fieldpea	4008	332	184	1000	5.3	50	100	150
soya	4374	452	240	1200	4	35	70	50
noug	2233	388	260	450	5.5	22.5	55	15
linseed	2353	420	212	550	5	35	70	35
sunflower	3546	322	248	700	5.3	12.5	25	10
sesame	4974	300	184	650	8	25	50	10

Table 11 Crop summary under best farm practices

Crops	Gross margin Birr/ha	Man'l labor Hrs/ha	Oxen labor Hrs/ha	Actual Yield Kgs/ha	Farm price Birr/kg	DAPc Kg/ha	UREAc Kg/ha	Seed rate Kg/ha
teff	9505	778	582	1800	6	120	120	30
wheat	9869	694	414	2600	5	145	145	150
maize	12678	454	230	4000	3.5	170	170	30
sorghum	8191	554	313	2500	3.5	50	50	15
faba	6282	532	212	2000	4.8	100	100	185
fieldpea	7877	465	212	2000	5.3	100	100	125
soya	8497	633	276	2400	4	70	70	50
noug	3725	543	299	800	5.5	55	55	15
linseed	3972	588	244	1000	5	70	70	35
sunflower	6838	451	285	1400	5.3	25	25	15
sesame	9638	420	212	1300	8	50	50	15

As it can be seen, maize has the highest gross margin per hectare and also a relatively low labor consumption. Wheat has almost the same gross margin, but by far consumes more labor. It is fair to say that cereals (teff, wheat, maize and sorghum) have a higher gross margin than the other crop families. Hence, it can be expected that the cereals will utilize most of the area allowed.

From the non-cereals, sesame earns the highest gross farm income. Its labor consumption is also remarkably low. It is followed by Soya that has a significant gross farm income but requires more hours of both man and oxen labor than other non-cereal crops. The other oil seed crops; noug and linseed have a disappointing gross margin. This is mainly due to their low yields. Sesame's yield is in the same neighborhood, but it benefits from its high price. In fact, sesame has the highest price of all the crops in the model.

5 Results of the model

This chapter will concentrate on the presentation and explanation of the main results of the model. The results to be discussed include model validation, the optimum cropping plan, the revenues and expenses, and the sensitivity analysis. These results are organized on the basis of farm sizes and farm practices. Farm size is chosen to analyze the effect of changes in farm sizes. Results will be presented for farm sizes of 1, 2, 5 and 10 hectares. Farms larger than 10 hectares are usually commercially owned and do not reflect peasant farming. Additionally, results will be presented and discussed for two kinds of farm practices: conventional and best farm practices.

5.1 Validation of the model

This section evaluates the consistency of the optimization model with the actual farm practice of the region. The previous chapter has described how farm realities of the region are molded in to the model. But models rarely reflect the real situation perfectly. Hence, there are some major settings of the GAMS model that deviate from the pure reality.

To quantify the effect of these inconsistencies, table 12 below compares the results of the actual cropping plan with the optimal cropping plan results for a farm size of 1.72 hectares. The average farm size in Ethiopia is 1.72 hectares. The table also gives the revenue and expense details of each plan along with the minimum farm size of each crop that is needed to meet the food demand of the family. The minimum farm sizes indicated in the last column are crop land sizes that should be grown to avoid buying food from external market. If the size of any crop falls short of the prescribed minimum in the cropping plan, there will be food expense which is bought from external market.

Table 12 Actual and optimal cropping plan results at the average farm size of 1.72 hectares

Crops	*Crop Shares in %*		*Crop size in hectares*		
	Actual Plan	Optimal plan	Actual Plan	Optimal plan	***Food in Hectares***
Cereals	**80%**	**67%**	**1.358**	**1.137**	**0.729**
Teff	30%	15%	0.516	0.258	0.258
Wheat	7%	3%	0.120	0.049	0.049
Sorghum	17%	9%	0.148	0.145	0.145
Maize	26%	40%	0.452	0.695	0.277
Pulses	**12%**	**3%**	**0.201**	**0.061**	**0.061**
Faba beans	9%	2.5%	0.141	0.043	0.043
Field peas	3%	0.5%	0.059	0.018	0.018
Oilseeds	**8%**	**30%**	**0.161**	**0.513**	**0.021**
Soya beans	0%	5%	0.000	0.083	0.000
Noug	6%	0%	0.106	0.000	0.014
Linseed	2%	0%	0.055	0.000	0.007
Sunflower	0%	0%	0.000	0.000	0.000
Sesame	0%	25%	0.000	0.430	0.000
Gross farm income	**4,223**	**4,819**			
Crop Sales	4,620	5,336			
Total Expenses	397	517			
Food expense	0	102			
Fertilizer exp.	397	407			
Interest exp.	0	9			
Labor Expense	0	0			
Seed Expense	0	0			

The biggest difference is related to the crop rotation rules specified in the model. Crop rotation rules of the model are well-structured in handling the three crop families; cereals, pulses and oilseeds. As specified in chapter 3, a maximum of 67% or 2/3rd of the total land might be assigned to cereals and the rest is reserved for pulses and oilseeds. However; in the actual situation, the cereals are grown roughly on 81% of the land in Jimma region and on 76% of the land in the country. In general, this is a result of high dependence on cereals. Cereals serve as the backbone of food security as a whole and their local demand exceeds that of other crop families.

Secondly, fertilizer and credit amounts allowed in the model are more likely to be different from the real practice. Amounts of fertilizer for facilitating crop growth are directly adopted from the CSA statistics with a slight adjustment. The slight adjustment refers to the fact that UREA and DAP amounts were considered to be applied in equal proportion for the sake of convenience. On the other hand, a credit of 1000 birr and 2000 birr per hectare is allowed in the conventional farming and best practice farming respectively. This is not necessarily the case in the actual practice. As a matter of fact, credit is rarely available to Ethiopian farmers.

Last but not least, labor planning of the model is more scientific and efficient than the actual farm practice. To assume that labor can be hired whenever the family labor falls short of the demands in some way overlooks the difficulties. In addition to this, the wage of labor hiring may be volatile based on the type of activity or the time in the labor calendar. For example, labor for harvesting may cost more than labor for soil tillage because it requires higher skill.

The points mentioned above are the major inconsistencies that can be attributed to the fact that the model represents only some parts of the farm reality in Ethiopia. The most important difference between the two plans as noted above is with regard to the crop rotation scheme. As it can be seen, cereals have a significant share in the actual crop growing practice of the region. Teff, wheat, sorghum and maize were grown over 80% of the land in the actual plan while they consumed the maximum allowed 67% of the land in the optimal plan. Teff and maize in particular have high shares in the actual plan with 30% and 26% of the land respectively. These two crops in combination consume more than half of the land available. As evidenced in the last column of the table, 0.258 and 0.277 hectare of teff and maize respectively are required to meet the food demand of these two crops. This clearly shows that teff and maize are the two most prominent crops used for food consumption in the region.

There will be yield available for sale for both maize and teff since the hectares in the actual plan (teff=0.516 and maize=0.452) are greater than the hectares needed for family food. However; in the optimal plan, even if both maize (40%) and teff (15%) have a great share of the land, but most of the land went to maize because of its high gross farm income. Under the optimal plan, teff is grown over the minimal land required for food. This indicates maize is available for sale, but not teff.

Another major crop which is available for sale in the optimal plan is sesame with 0.430 hectares in the optimal plan and with zero hectare required for food. Same explanation can be made for soya bean. In fact, the biggest difference between the two plans in terms of oilseeds is related to the role of soya bean and sesame. Soya and sesame have a negligible share in the actual plan. But these two crops utilize 29% of the land as far as the optimal cropping plan is concerned. In the actual plan, it is noug and linseed with a share of 8% of the land that represents the participation of oilseeds. Unfortunately, both suffer from a lower gross farm income as shown in the summary crop information in chapter 3. Crops can be included in the actual plan even if they have a low gross farm income since their land sizes are predetermined based on the overall farm practice of the region. This shows noug and linseed are the two most commonly grown and consumed oilseed crops, which is evidenced by the minimum size of land (0.014 and 0.007 hectares) needed in the food column.

On the other hand, the crop sizes in the optimal plan are not as predetermined as they are in the actual plan. The guiding factor for the optimal plan in determining the land size of crops is the minimum food requirement in hectares. However, under optimization, the plan can flexibly avoid growing some crops that do not have high gross farm income to be purchased and use the land left for growing more crops with a better gross farm income figures. This flexibility is proven especially for the cereals and oilseeds. Under cereals, maize has the highest gross farm income. Thus the other cereals (teff, wheat and sorghum) are only grown at 0.258, 0.049 and 0.145 hectares respectively so that the rest of the land available goes to maize.

This adjustment allows growing maize over 0.695 hectares. The indicated size is the maximum land size maize can have, mainly due to the crop rotation restriction that assigns 67% of the land to cereals. Assessing the oilseed participation under the optimal plan, the minimum land required for nueg and linseed is not met. This is because purchasing these crops from the external market and transferring these minimum land requirements to two other oilseed crops, soya bean and sesame has a more favorable impact on the gross farm income. The optimal plan does not include purchasing pulses (faba and field peas) from the external as evidenced by the land required which are 0.043 and 0.018 hectares respectively.

Hence, the amount of land saved from not growing nueg and linseed and from growing faba and field pea went to sesame and soya bean. The first land allotment went to sesame and as a result, 0.430 hectares of sesame was grown. This is 25% of the land which is the maximum allowed share for an oilseed. The second most attractive crop financially was soya bean and the rest of the land went to it. As a result, soya bean is grown over 0.083 hectares of land grown. This flexible land adjustment is the primary reason behind the better gross farm income figures under the optimal cropping plan.

Breaking down the details of the expenses, food expense in the actual plan are zero, but 102 birr in the optimal plan. The food expense in the optimal plan is not consistent with the actual situation. As seen in table 12, the actual plan covers all the crop size required to meet the food demand. The optimal plan doesn't meet those requirements for noug and linseed since they are not included in the optimal plan. Thus, the 102 birr expense is directly related with purchasing noug and linseed from the food market. As a result of this change, the sales of the optimal plan are much higher than while the costs of the actual plan are lower. Fertilizer costs are only a little higher. So the difference in the costs is mainly explained by the possibility of food expenses.

5.2 Conventional practice results

This section presents the optimization results of the model for the conventional farm practices. Conventional farm practices refer to the traditional farming style that are predominant in Ethiopia. This includes farmers that are not in especial government programs and are not participants of farm experiments being conducted by various agricultural institutions.

5.2.1 Optimum plan results

Table 13 presents the three types of key results of conventional farm practices. First, it shows at different farm sizes the optimal cropping plan in hectares with the respective percentages along with minimum crop size required to meet food demand.

Secondly, it summarizes the revenues, expenses and the gross farm income as a result of the optimal crop plans. Thirdly, it summarizes the status of major resources in the model.

Table 13 Optimal cropping plan and economic results for conventional farm practices at different farm sizes

Crop	1 ha	%	2 ha	%	5 ha	%	10 ha	%	Food in hectares
Cereals		**67**		**67**		**67**		**67**	**0.729**
Teff	0.258	25.8	0.258	12.9	0.258	5.2	0.258	2.6	0.258
Wheat	0.049	4.9	0.049	2.4	0.431	8.6	1.264	12.6	0.049
Sorghum	0.083	8.3	0.145	7.2	0.145	2.9	0.145	1.5	0.145
Maize	0.277	27.7	0.882	44.1	2.500	50	5.000	50	0.277
Pulses		**6**		**3**		**1.5**		**0.6**	**0.061**
Faba	0.043	4.3	0.043	2.1	0.043	0.9	0.043	0.4	0.043
Field pea	0.018	1.8	0.018	0.9	0.018	0.4	0.018	0.2	0.018
Oilseeds		**27**		**30**		**32**		**32.7**	**0.021**
Soya	0.023	2.3	0.106	5.3	0.656	13	1.892	18.9	0.000
Noug	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.014
Linseed	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.007
Sunflower	0.000	0.0	0.000	0.3	0.000	0.0	0.000	0.0	0.000
Sesame	0.250	25	0.500	25	0.950	19	1.381	13.8	0.000
Resource Use									
Land	Fully used		Fully used		Fully used		Fully used		
Own Man Labor	Not fully used		Not fully used		Not fully used		Fully used*		
Own Oxen Labor	Not fully used		Not fully used		Fully used*		Fully used*		
Credit	Used		Used		used		used		
Revenues & Expenses									
Gross farm income		605		6, 435		23, 457		50,379	
Crop Sales		1385		7, 030		24, 851		54, 296	
Total Expense		780		595		1,394		3,917	
Food Expense		501		102		102		102	
Fertilizer Expense		226		484		1,199		2,285	
Interest Expense		53		10		14		142	
Labor expense (Man)		0		0		0		382	
Labor Expense (Ox)		0		0		79		996	
Seed Expense		0		0		0		0	
Gross farm income per ha		605		3,218		4,691		5,038	

**Both man and oxen labor are fully used only in some periods. Note that the expression 'fully used' is a short expression for 'fully used in some periods'.*

The cropping plan distribution is more or less the same for all farm sizes except for 1 hectare. As expected, maize takes the highest share in all optimum cropping plans. For all farm sizes bigger than 2 hectares, 50% of the land is assigned to maize which is the maximum allowed land. In the 1 hectare land distribution, maize is grown on only 0.277 hectares which is equal to the minimum land size required to meet food demand. This shows maize is not sold for generating revenue. This in turn indicates 1 hectare is too small to satisfy the food demand of the family and have an extra land available for the crops with an attractive gross farm income. This, for instance, is clearly witnessed by the crop size of cereals. The size of all cereals except sorghum were only able to meet the minimum required food size. Teff, maize, and wheat only were grown over 0.258, 0.049 and 0.277 hectares respectively, equal to the hectares of food. Sorghum was grown over 0.083, which is even less than the minimal size required (0.145 hectares). This means yield of sorghum equivalent to 0.06 hectares will be outsourced or purchased. The sum of the size of cereals mentioned under the 1 hectare plan above is 0.667 hectares. This sum has already reached the maximum allowed land for cereals, i.e., 67%.

Hence, it is not possible to grow maize beyond the minimum requirement, which negatively influenced the gross farm income for the 1 hectare plan. The absence of crop sales with high gross farm income like maize clearly indicates the impact of having a small farm size. There is no particular crop with a very high share of the land under 1 hectare and as seen in the resource usage status, land is the only resource that is fully utilized. The critical resource shortage explains the uncharacteristically low gross farm income per hectare, shown on the last row. The gross farm income per hectare increased dramatically from 605 to 3,218 birr after increasing farm size to 2 hectares.

Soya bean and sesame are the only two crops that will be sold under 1 hectare plan. Soya bean and sesame are not needed for food and yet have a share in the optimal plan. Thus, all of their yield will be used for sales. Nueg and linseed are not grown for economic reasons while the pulses (faba=.043 hectares, field pea=0.018 hectares) are grown to meet the minimal food requirement. The extra land available from these distributions went to sesame and soya bean. The first land allotment was attributed to sesame until it reached the maximum land share allowed (25%), then a tiny amount of land (0.023 hectares) went to soya bean.

In the 2, 5 and 10 hectare plans, share of maize is greater than 0.277 hectares. Hence, there is maize available for crop sales. Wheat is sold in 5 and 10 hectare optimal plans, but not at the 2 hectare plan. Other cereals (Sorghum and Teff) had a contribution in the optimal plans that are only sufficient to meet the food demand. The advantage of having bigger farm sizes such as these is the possibility of extra land available for growing crops with high gross farm income over large land sizes. This boosts the crop sales significantly. The sum of minimum land required for food under cereals is 0.729 hectares (the sum of 0.258, 0.049, 0.145 and 0.277 hectares). For example, under the 5 hectare crop plan, 67% of the land (3.35 hectares) is available to be utilized by cereals. Thus, there will be a big chunk of land to go beyond the minimum requirements. In doing so, priority is given to crops with high gross margin (See table 10). As a result, the share of maize was increased until the maximum allowed land(50%) is reached. Growing wheat above the minimum land size required was even possible at the 5 hectare plan as it has a share of 0.431 hectares. This analogy is also true for the 10 hectare plan.

With regard to oilseeds, soya bean and sesame has almost the same role in the 2,5 and 10 hectare plans. In general, cereals have consumed the maximum allowed land proportion, i.e., 67%. Out of what is left for other crops that are not cereals, most of the land is consumed by sesame and soya bean. Sesame and soya bean shared more than 30% of the land between themselves. In the case of all farm sizes, soya bean and sesame had a share of more than 25% of the land. As discussed under the 1 hectare plan, nueg and linseed were purchased and pulses (faba beans and field peas) were grown at their minimal level, leaving a substantial land to be utilized by sesame and soya bean.

Land is a limiting factor for all farm sizes. This indicates land is the only resource in the model limiting the gross farm income in all the cases. Oxen labor becomes a binding factor for some periods with labor shortages for farm sizes greater than 5, while human labor becomes limiting only after 10 hectares and beyond. This shows oxen labor has higher economic value and is more scarce than the human labor. It is important to note that labor shortage is not faced in all periods. Labor will always be idle in some periods. It is only in peak periods like period 7 (see Appendix 1 and 2) that labor is fully used and hiring is needed. Additionally, credit is used in all farm sizes, but in all cases, the maximum allowed credit is not reached. Hence, credit is a critical resource of the model, but not binding.

Assessing the revenue and expense figures, food cost is the highest cost incurred for the 1 hectare size and it is the only case where the food cost exceeded the fertilizer cost. In fact, food cost of 501 birr under the 1 hectare plan is larger than the other observed food costs of 102 birr for the other farm sizes. The reason behind the high food cost under 1 hectare relates to the inclusion of sorghum in the food purchase. In all farm sizes except 1 hectare, noug and linseed are the only two crops that are not grown meet the food demand and need to be purchased. But under 1 hectare, share of sorghum, noug and linseed are not sufficient for food demand. Thus, these three crops are purchased from the market to keep the family from food insecurity.

Fertilizer expense is directly related with the farm sizes. The expense doubled as farm size is increased from 1 to 2 hectare and from 5 to 10 hectares. There is no labor expense until 5 hectare is reached. And the first labor type that was fully utilized and hired was an oxen labor. Thus, the 79 birr labor expense in relation to the 5 hectare crop plan resulted from oxen hiring. Under 10 hectares, there is a significantly high labor expense. Both man and oxen labor were hired. That is why interest expense was much higher form the rest of the farm sizes as cash was needed for compensation.

The food expense explains the change in the gross farm income from 1 to 2 hectares. The food expense decreases dramatically. Besides, the 1 hectare farm size has proven to be small to provide a significant amount of crop yields for sales. Hence the crop sales per hectare was significantly larger under 2 hectares(3,015 birr) , compared to 1 hectare (1,385 birr).

The gross farm income per hectare increased by 1473 birr moving from 2 to 5 hectares while it jumped by only 347 birr in shifting from 5 to 10 hectares. There are two factors in the increase moving from 2 to 5 hectares. The first one is due to the simple reason that the food expense stayed the same. Food expense was 102 birr for both farm sizes. Thus the same cost for two different farm sizes means a lower cost per hectare for the larger farm size. The other reason was the increase in sales per hectare. Crop sales per hectare under the 2 hectare plan is 3, 015 while it is 4, 970 under the 5 hectare plan. These two combinations caused the higher gross farm income per hectare. The increase in gross farm income per hectare in moving from 5 to 10 hectares is also explained by these two factors. But there were other reasons that contributed for the low increase (347 birr). First, the farm size more than doubled in shifting from 2 to 5 hectares. This gives it more advantage. Secondly, even if the crop sales per hectare boomed from 4,970 birr to 5,430 birr, the need for more cash due to more labor expenses increased the interest expense and the labor expense per hectare by more than 10 times. Labor expense was higher since the labor available (the family size) stayed the same as the farm sizes increased.

5.2.2 Sensitivity analysis

Sensitivity analysis was done in order to capture the effects of major variables. It is one of the several measures to evaluate how representative a model is (Kruseman, 2000). This section will outline the changes in the optimal results by altering the status of variables such as farm gate price, labor availability and credit level. Two kinds of sensitivities were undertaken. The first is price changes for both inputs and outputs in the model. Variation in price of some crops and changes in costs of labor are included in this division. The second type is change of constraint. The effects of either relaxing or making some constraints more strict will be discussed.

The 5 hectare solution report will be used as a basis for comparisons. This farm size is chosen for two reasons. First, it is large enough to clearly indicate the effect of some variables. For instance, the effect of decreasing labor availability doesn't come in to play until 5 hectare farm size is reached. Secondly, 5 hectare can be used as a typical cropping plan distribution. The cropping plan of 5 hectares is nearly uniform with all the plans greater than 2 hectares.

5.2.2.1 Increase in price of soya bean and sunflower

Table 14 presents how the optimal cropping plan changes with the increase in price of Soya beans and Sunflower. With the increasing international market demand and the possible diversification of food sources in Ethiopia, it is foreseeable that their price will go up. So the question to be answered is how far their prices should be increased until their share reaches maximum allowed land. The price will be increased by 0.5 birr step by step.

Table 14 Price* increase impacts of soya bean and sunflowers at the 5 hectare conventional farm

Crop	Base	Increase by 0.5 birr	Increase by 1.00 birr	Increase by 1.5 birr
Crops				
Cereals	**67%**	**67%**	**67%**	**67%**
Teff	0.258	0.258	0.258	0.258
Wheat	0.431	0.431	0.431	0.431
Sorghum	0.145	0.145	0.145	0.145
Maize	2.500	2.500	2.500	2.500
Pulses	**1.2%**	**0.94%**	**0.36%**	**0%**
Faba	0.043	0.029	0.0	0.00
Field pea	0.018	0.018	0.018	0.000
Oilseeds	**32%**	**32%**	**33%**	**33%**
Soya	0.656	1.203	1.232	1.250
Noug	0.000	0.000	0.000	0.000
Linseed	0.000	0.000	0.000	0.000
Sunflower	0.000	0.000	0.000	0.000
Sesame	0.950	0.417	0.417	0.417
Revenues and Expenses				
Gross farm income	23,337	24, 078	24, 785	25,329
Crop Sales	24,758	25,328	26,188	27,008
Total Expense	1,421	1,250	1,403	1,509
Food Expense	122	169	312	410
Fertilizer Expense	1,202	1,040	1,035	1,031
Interest Expense	17	0	15	26
Labor Expense (man)	0	0	0	0
labor Expense (ox)	79	41	41	42
Seed Expense	1	0	0	0

** base price is for soya beans 4ETB/kg and 5.25ETB/kg*

Soya bean is by far more responsive to the price increase than sunflower. Sunflower's share in the optimal plan did not change despite the price jumps, even for high price increases. Soya bean is more attractive financially and takes the role of inclusion. Additionally, soya bean's land share did not require a dramatic price increase to come in to play. With only a 0.5 birr increase in price, soya bean's share jumped from 0.656 to 1.203, increased by almost a double. After a 0.5 birr increase, the land proportion increased slowly until it reaches the maximum allowed, i.e 25% of the total land. The price of soya bean has to increase by 1.5 birr before it reaches the maximum allowed land as shown. This shows with a slight increase in demand or price of soya bean, it has a great potential to be a financially preferable crop to the farmers.

With every 0.5 birr increase in price of both the crops the gross farm income showed a steady growth of 740 birr. This figure is impressive when the land improvement of the crops is particularly referenced. For instance, between 0.5 and 1.00 birr price jump, the farm size of soya bean enlarged by only 0.02 hectares out of the 5 hectares available and yet the gross farm income improvement is still 620 birr.

5.2.2.2 Low labor supply

Manual and oxen labor are among the limiting resources for especially large farm sizes. In Ethiopia, in areas with extreme weather conditions such as Humeara, farm labor availability is usually low due to low population density. In these kind of areas, wage rates are often high. This section attempts to assess the effect of these adverse conditions with significance of such areas. Two labor conditions with high wage rate will be analyzed; labor availability of 30% less than what is assumed in the model and 50% less. Along with the decrease in labor availability, wage rate for man labor is increased to 2.5 birr and oxen labor is rocketed to 1.5 birr.

Table 15 presents how the optimal cropping plan and economic results change as a result of having a lower labor supply and higher wage rate at the same time.

Table 15 Impact of low labor supply and higher labor price at conventional farm size of 5 hectares

Crop	Base	30% Less	50% Less	Food in hectares
Cereals	**67%**	**67%**	**67%**	**0.729**
Teff	0.258	0.313	0.404	0.258
Wheat	0.431	0.375	0.284	0.049
Sorghum	0.145	0.145	0.145	0.145
Maize	2.500	2.500	2.500	0.277
Pulses	**1%**	**1%**	**1%**	**0.061**
Faba	0.043	0.043	0.043	0.043
Field pea	0.018	0.018	0.018	0.018
Oilseeds	**32%**	**32%**	**32%**	**0.021**
Soya	0.656	0.801	1.189	0.000
Noug	0.000	0.000	0.000	0.014
Linseed	0.000	0.000	0.000	0.007
Sunflower	0.000	0.000	0.000	0.000
Sesame	0.950	0.805	0.417	0.000
Resource Use				
Own Man Labor	Not fully used	Fully used*	Fully used*	
Own Oxen Labor	Fully used*	Fully used*	Fully used*	
Gross farm income	23, 457	22,852	22, 048	
Crop Sales	24, 851	24,529	24, 758	
Total Expense	1,394	1,677	2, 710	
Food Expense	102	102	102	
Fertilizer Expense	1,199	1,033	1, 153	
Interest Expense	14	43	146	
Labor Expense	79	500	1,310	
Seed Expense	0	0	0	

**Both man and oxen labor are fully used only in some periods. Note that the expression 'fully used' is a short expression for 'fully used in some periods'.*

Surprisingly, the effect of adverse labor conditions is not as worse as expected. The gross farm income decreased by only 600 birr (12.5%) as a result of depressing the labor by 30% and only by 1400 birr (6%) from cutting the labor by 50%. The increase

is mainly from an increase of labor expense. Throughout the labor force cuts, the labor expense exploded from 79 birr to 500 birr and to 1,310 birr with the labor cuts.
The cropping plan changed throughout the decrease in labor supply. The most important changes observed are related with the two crops from cereals and two from oilseed crop families. The changes have the same trend. From the cereals side, there was a rise in share of teff from 0.258 ha to 0.404 ha and the land share of wheat was downsized from 0.431 hectares to 0.284 ha. And from the oilseeds side, the size of soya bean rose to 1.189 hectares while Sesame's size fell to 0.417 hectares. As it can be seen from the labor consumptions in Appendix 1 and 2, teff needs more labor than wheat, while soya bean consumes more labor than sesame in a period with the highest labor shortage; which is period 7. Taking all crops in to account, period 7 requires 352 hours of man labor and 576 hours of oxen labor as compared to 192 hours of man and oxen labor available, more than any other period. In the model, period 7 represents the days ranging from June 20 to July 3 GC which is a rainy season in Jimma. Farmers has to plant a lot of crops in this period to gain advantage of the rain.

The logical adjustment due to the low labor supply would have been the decrease in the land share of teff and soya bean and the increase in the land share of wheat and sesame. However, the land share for teff and soya bean increased while that of wheat and sesame decreased. This means another factor besides labor supply impacted the cropping plan. In case of wheat, increasing its land share as a result of low labor supply would have mean a decrease in the land share of one of the other cereals (teff, sorghum and maize). But, it can be noticed that teff and sorghum are on the minimum level of hectares to meet food demand and maize has already reached the maximum possible amount of hectares. The share of maize could not be decreased since it is the crop with the highest gross margin. And in case of sorghum and teff, decreasing their share means buying some amount of sorghum and teff from the external market for food. And buying crops from external market is more expensive than hiring more labor. As mentioned under section 4.5.5, to buy a kg of teff and sorghum, a farmer pays 7.5 birr (6*1.25) and roughly 4.4 (3.5*1.25) birr per kg respectively. Whereas, to hire an extra unit of man and oxen labor, a farmer is expected to pay an extra 2.5 birr and 1.5 birr per hour respectively.

Thus, it is more economical to pay for more labor hours than buy extra food. Accordingly, the options to adjust for low labor supply is to further increase the land share of maize, sorghum and teff to avoid the buying of more food. The land share of maize cannot be increased since it is has reached the maximum allowed land. As a result, increasing the share of teff is preferred to sorghum since teff has a higher gross margin. As a result, the share of teff was increased throughout decreasing the supply of labor to 30% and 50% respectively. And the land share of wheat has to be decreased to remain within the allowed land share for cereals.

5.3 Best farm practice results

This section discusses the optimization results of the model for the best farm practices. Best farm practices refer to the farmers involved in especial government programs and follow specific scientific recommendations of farm research institutions. This practices usually result in higher yields, but at high costs and greater labor and credit utilization.

5.3.1 Optimum plan results

Table 16 shows the key results of best farm practices. As done for the conventional farm practices, the table will combine farm sizes of the crops in the optimal along food requirement in hectares. The revenues and expenses resulting from the optimal cropping plans are also provided.

Table 16 Optimal crop plan results for best farm practices at different farm sizes

Crop	1 ha	%	2 ha	%	5 ha	%	10 ha	%	Food
Cereals		**67**		**67**		**67**		**66.7**	
Teff	0.139	13.9	0.139	6.9	0.724	14.5	0.581	5.8	**0.139**
Wheat	0.023	2.3	0.108	5.4	0.023	0.5	1.000	10	**0.023**
Sorghum	0.005	5	0.086	4.5	0.086	1.7	0.086	0.9	**0.086**
Maize	0.500	50	1.000	50	2.500	50	5.000	50	**0.135**
Pulses		**2**		**1**		**1.5**		**0.3**	
Faba	0.018	1.8	0.018	0.9	0.018	0.4	0.018	0.2	**0.018**
Field pea	0.008	0.8	0.008	0.4	0.008	0.2	0.008	0.1	**0.008**
Oilseeds		**31**		**32**		**32**		**33**	
Soya	0.058	5.8	0.142	7.1	0.392	7.8	0.808	8.1	**0.000**
Noug	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0	**0.007**
Linseed	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0	**0.003**
Sunflower	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0	**0.000**
Sesame	0.250	25	0.500	25	1.250	25	2.500	25	**0.000**

	1 ha	2 ha	5 ha	10 ha
Resource Use				
Land	Fully used	Fully used	Fully used	Fully used
Own Man Labor	Not fully used	Not fully used	Fully Used*	Fully used*
Own Oxen Labor	Not fully used	Not fully used	Fully used*	Fully used*
Revenues & Expenses				
Gross farm income	6,248	17,711	51,073	105,243
Crop Sales	8,340	19,850	56,262	119,411
Total Expense	2,092	2,139	5,189	14,168
Food Expense	991	102	102	102
Fertilizer Expense	296	599	1,466	3,028
Credit Expense	184	164	394	1,167
Labor expense (man)	0	0	314	1855
Labor Expense (ox)	0	0	174	918
Protection Expense	150	300	750	1,500
Seed Expense	472	974	1, 990	5,598

**Both man and oxen labor are fully used only in some periods. Note that the expression 'fully used' is a short expression for 'fully used in some periods'.*

Despite the optimum cropping plan distribution of conventional farm practices, the optimal plans of best farm practices are more uniform for all farm sizes including 1 hectare. Maize takes up 50% of the land in all optimum cropping plans which wasn't the case for the conventional farm practices. The major reason for this is related with the higher yields of best farm practices, usually double of the conventional practices. Higher yields enable the best farm practice cropping plan to cover the minimum food requirement with a much smaller farm sizes. For instance, farm sizes of 0.258(teff), 0.145(sorghum) and 0.043(faba) were required to meet the food demand of the respective crops. But under the best practices, these figures were reduced to 0.139(teff), 0.086(sorghum) and 0.018(faba). This provides more land available for sales and revenue generation of crops with high gross farm income. Pulses are grown only to meet the food requirement with a crop size of 0.018 and 0.008 hectares, as seen forr faba and field pea respectively.

Under cereals, teff and wheat are grown to meet the minimum food requirement in the 1 and 2 hectare plans. But they are sold under 5 and 10 hectare cropping plan as their respective land shares exceeded the minimum hectare needed to secure food demand. On the whole, cereals have once again consumed the maximum allowed land proportion, i.e., 67%. This shows cereals are still more attractive financially than the other crop families. As expected, soya bean and sesame utilized most of the land left from cereals. Sesame was grown at a maximum allowed land share. Soya beans utilize the remaining land. This proves these two crops are the most profitable crops to grow in rotating with cereals. Rotating as discussed above is necessary to avoid the deterring effects of mono-cropping.

Assessing the resource usage influencing the cropping plan, land is once again a common limiting factor throughout all plans. As it can be recalled, oxen labor becomes a binding factor in some periods for farm sizes of 5, while human labor becomes limiting only at 10 hectares under the conventional farm practices. However under best farm practices, human labor becomes binding before oxen labor. This is noted from the details of GAMS solution report where more human labor is hired than the oxen labor. Credit was used in the crop plans of all farm sizes but not to the fullest extent. But the amount of credit used under best farm practices is by far greater than used under conventional practices. This is due to the high level of cash related expenses under best farm practices. The cash expenses and the relation with credit will be discussed in the upcoming paragraphs.

As far as revenue and expense figures are concerned, there is a new cost category under the best farm practices, this is indicated as crop protection expense. This is the cost of extra care required under best farm practices that are not prevalent under the conventional farm practices. It is linearly related with the farm size like the fertilizer cost. It increased from 150 to 300 birr as farm size rise from 1 hectare to 2 hectares. Roughly, the same analysis can be made for the fertilizer cost. Gross farm income is reasonably high even for 1 hectare. It was only about 600 birr under 1 hectare for the conventional farm practice. This figure is as high as 6,248 birr in the best farm practices. The major reason for this normally high gross farm income as indicated has to do with the higher yields of best farm practices, usually double of the conventional practices. This enables the best farm practices to cover the minimum food requirement with a much smaller farm sizes. This provides the opportunity making more land available for sales and revenue generation.

Food cost is still the highest cost incurred for the 1 hectare size and it is the only case where the food cost exceeded the fertilizer cost. Beyond 2 hectares, the food cost remained constant at 102 birr which is of course incurred for purchasing noug and linseed since the minimum threshold of them are not met in the optimum crop plans. Additional food purchase caused by sorghum is the reason behind the unusually high food cost of the 1 hectare situation. There is no labor expense until 5 hectare is reached. But it is important to note that contrary to the conventional farm practice results, human labor costs (314 birr) were higher than oxen hiring costs (174 birr) under the best practices. This is partly due to the extra human intervention and care required to keep the crops in the best possible conditions.

Another important distinction between the conventional and best farm practice results is the level of interest expense. Interest expenses are relatively much higher for best practices. Interest expense is 184 birr under the 1 hectare cropping plan. This means a credit of 1840 birr is used as the cost of borrowing was set at 10%. The credit taken is only 160 birr from the maximum allowed credit, i.e., 2000 birr per hectare. Clearly, interest expenses are more significant for the 1 hectare farm size. For instance, the credit taken per hectare under the 1 hectare plan is 1, 840 birr while it is 820 birr under 2 hectares and so on. However, in general, this points to the importance of credit for the best farm practices because it involves high level of cash related expenses. The unique cost that requires large amount of cash in fact was the seed expense. Seed expense was uncharacteristically the highest expense of all the expenses under best practices. This is expected since best seed varieties can only be used and the seeds can only be bought from a special seed market at a remarkably high price.

5.3.2 Sensitivity analysis

Sensitivity analysis was also done for the best farm practices. Changes made for the conventional farm practices will be repeated with an extra analysis in this case. That additional sensitivity analysis is made for discussing the effect of changing the level of credit available. Credit has proven to be a big player in the best farm practices due to higher cash expenses. The other variables to be discussed are the increase in price of oilseeds, and decrease of labor force.

5.3.2.1 Increasing price of soya bean and sunflower

Table 17 below presents how the optimal cropping plan changes with the increase in price of Soya beans and Sunflower under the best farm practices.

Table 17 Increasing price of soya bean (4.0) and sunflower (5.25) at a farm size of 5 hectares.

Crop	Base	Increase by 0.5	Increase by 1.00	Increase by 1.5	Increase by 2.0
Crops					
Cereals	**67%**	**67%**	**66%**	**66%**	**66%**
Teff	0.724	0.329	0.330	0.330	0.325
Wheat	0.023	0.419	0.417	0.417	0.422
Sorghum	0.086	0.086	0.086	0.086	0.086
Maize	2.500	2.500	2.500	2.500	2.500
Pulses	**0.5%**	**0.5%**	**0.3%**	**0.3%**	**0%**
Faba	0.018	0.018	0.000	0.000	0.000
Field pea	0.008	0.008	0.008	0.008	0.000
Oilseds	**32.5%**	**32.5%**	**32.7%**	**32.7%**	**33.3%**
Soya	**0.392**	**1.225**	**1.242**	**1.242**	**1.250**
Noug	0.000	0.000	0.000	0.000	0.000
Linseed	0.000	0.000	0.000	0.000	0.000
Sunflower	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Sesame	1.250	0.417	0.417	0.417	0.417
Revenues and Expenses					
Gross farm income	51,073	51,877	53,258	54,646	56,040
Crop Sales	56,262	57,936	59,612	61,103	62,714
Total Expense	5,189	6,059	6,354	6,457	6,673
Food Expense	102	105	312	312	410
Fertilizer Expense	1,466	1,321	1,321	1,321	1,322
Interest Expense	394	481	510	521	542
Labor Expense	488	444	446	446	447
labor Expense(man)	314	291	293	293	294
Labor Expense (ox)	174	153	153	153	153
Crop Protection Expense	750	750	750	750	750
Seed Expense	1, 990	2,959	3,014	3,108	3,202

The response of soya and sesame to the price increases is almost similar to the observation under the conventional farm practices. Soya bean is still more responsive to the price increase than sunflower. The only difference under this plan is that a price has to be increased by 2.00 for one of the crops(soya bean) to reach the maximum allowed share of land. This is partly due to the relatively low crop share in the starting point (0.392 hectares). Sunflower's share in the optimal plan did not change despite the price jumps. With every 0.5 birr increase in price of both the crops the gross farm income showed a steady growth of 800 birr per hectare.

5.3.2.2 Credit

Credit is the main constraint with the biggest impact on the results of the optimal crop plans. Table 18 presents the changes in the optimal plans resulting from minimizing the allowed credit per hectare from 2000 birr to 250birr, 500 birr and 1000 birr. Ethiopian farmers constantly face lack of sufficient credit availability and it is important to have a prism of lower credits.

Table 18 Changes in credit level at a (best practice) farm size of 5 hectares

Crop	Base (Credit 2000)	Credit 1000	Credit 500	Credit 250
Cereals	**3.333**	**3.333**	**3.334**	**2.858**
Teff	0.724	0.724	0.139	0.139
Wheat	0.023	0.023	0.023	0.023
Sorghum	0.086	0.086	0.813	0.446
Maize	2.500	2.500	2.359	2.250
Pulses	**0.026**	**0.026**	**0.026**	**0.026**
Faba	0.018	0.018	0.018	0.018
Field pea	0.008	0.008	0.008	0.008
Oilseeds	**1.642**	**1.642**	**0.918**	**0.026**
Soya	0.392	0.392	0.511	0.000
Noug	0.000	0.000	0.013	0.013
Linseed	0.000	0.000	0.005	0.005
Sunflower	0.000	0.000	0.000	0.004
Sesame	1.250	1.250	0.389	0.004
Resource Use				
Credit	Not fully used	Not fully used	Fully used	Fully used
Land	Fully Used	Fully used	Not fully used	Not fully used
Labor	Fully used	Fully used	Fully used	Not fully used
Gross farm income	**51,073**	**51,073**	**42,764**	**30,329**
Crop Sales	56,262	56,262	46,514	32,829
Total Expense	5,189	5,189	3,750	2,500
Food Expense	102	102	0	0
Fertilizer Expense	1,466	1,466	1,243	967
Interest Expense	394	394	250	125
Labor Expense	488	488	104	0
Labor Expense(man)	314	314	104	0
Labor Expense (ox)	174	174	0	0
Crop Protection Expense	750	750	641	435
Seed Expense	1, 990	1,990	1,512	973

As it can be seen, low credit has an extremely adverse impact on both the resource usage and gross farm income. The gross farm income retains its normal stature when the credit is set at 1000 birr per hectare and above. But it decreased by more than 20,000 birr from setting the credit to 250 birr per hectare and decreased by just less than 10,000 birr as a result of a 500 birr per hectare credit and working capital. Credit didn't prove to be of a great influence under the conventional farm practice. Relatively low level of farm expenses in the conventional farm practice helped preserve the stability of gross farm income with lower credit availabilities.

The major reason behind the sharp fall in the gross farm income is mainly related with the amount of land used. Not all of the land available was used under the 250 and 500 birr per hectare credit. This adversely decreases the sales since lower land use means lower crop yield available for consumption and sales. Under a credit of 250 birr per hectare, only 3.824 hectares of the 5 hectares available was utilized. This is due to the fact that a credit of 250 birr per hectare is too low to meet the cash expenses incurred from operating on 5 hectares. Consequently, the maximum credit allowed was utilized. An interest expense of 125 birr results from a 10% credit expense of 1250 birr (250 birr * 5 hectares). The same can be said about the 500 birr credit per hectare with an interest expense of 250 birr.

5.3.2.3 Low labor supply

Table 19 presents how the optimal cropping plan and economic results change as a result of having a lower labor supply and higher wage rate at the same time.

Table 19 Impact of low labor supply at farm size of 5 hectares

Crop	**Base**	**30% Less**	**50% less**	**Food**
Cereals	**3.334**	**3.334**	**3.334**	
Teff	0.724	0.458	0.247	**0.139**
Wheat	0.023	0.290	0.500	**0.023**
Sorghum	0.086	0.086	0.086	**0.086**
Maize	2.500	2.500	2.500	**0.135**
Pulses	**0.026**	**0.026**	**0.026**	
Faba beans	0.018	0.018	0.018	**0.018**
Field pea	0.008	0.008	0.008	**0.008**
Oilseeds	**1.642**	**1.642**	**1.642**	
Soya	0.392	0.392	0.392	**0.000**
Noug	0.000	0.000	0.000	**0.007**
Linseed	0.000	0.000	0.000	**0.003**
Sunflower	0.000	0.000	0.000	**0.000**
Sesame	1.250	1.250	1.250	**0.000**
Resource Use				
Own Man Labor	Fully used*	Fully used*	Fully used*	
Own Oxen Labor	Fully used*	Fully used*	Fully used*	
Gross farm income	51,073	49,546	48,654	
Crop Sales	56,262	56,849	57,311	
Total Expense	5,189	7,303	8,657	
Food Expense	102	102	102	
Fertilizer Expense	1,466	1,494	1,516	
Interest Expense	394	605	741	
Labor Expense	488	1,906	2,743	
Labor Expense (man)	314	1, 037	1782	
Labor Expense (ox)	174	869	1231	
Crop Protection Expense	750	750	750	
Seed Expense	1, 990	2,446	2,806	

**Both man and oxen labor are fully used only in some periods. Note that the expression 'fully used' is a short expression for 'fully used in some periods'.*

The effect of adverse labor conditions is again not as worse as expected. The gross farm income decreased by only 1,527 birr (2.7%) as a result of depressing the labor by 30% and only by 2,419 birr (4.8 %) from cutting the labor by 50%. The increase is mainly from an increase of labor expense. Throughout the labor force cuts, the labor expense increased from 488 birr to 1,906 birr and to 2,743 birr with the labor cuts.

The cropping plan changed throughout the decrease in labor supply. There was a rise in share of wheat from 0.023 ha to 0.290 ha and the land share of teff was downsized from 0.724 hectares to 0.458 ha. As seen in Appendix 1 and 2, teff needs more man and oxen labor than wheat in a period with the highest labor shortage and that is period 7. In the model, period 7 represents the days ranging from June 20 to July 3 GC which is a rainy season in Jimma. Farmers has to plant a lot of crops in this period to gain advantage of the rain.

Despite what was observed under the conventional farming, the logical adjustment due to the low labor supply holds under the best farm practices. The share of a crop with lower labor requirement in period 7(wheat) increased while the share of a crop with higher labor requirement (teff) decreased. This is because all the land shares of the cereals under the base have already met the minimum food requirement. There was no need to decrease a share of crops that are on the minimum level of hectares to meet the food demand. As shown in table 19, teff, wheat, sorghum and maize need 0.139, 0.023, 0.086 and 0.135 hectares to meet the food demand which is already met in the 5 hectare plan. Thus, the share of wheat can be increased without any additional forms of cost, except labor cost. As a result, the share of teff decreased and that of wheat increased.

6 Discussions, conclusions and recommendations

This final chapter broadens the discussion of preceding chapters to issues that are related to major methodological choices and the overall implication of model results. In section 6.1, major discussion points related to methodological issues are raised. In section 6.2, some points derived from empirical results of this thesis are analyzed. Section 6.3, general conclusions from this research are given. Section 6.4 presents various recommendations and ideas for further research.

6.1 Methodological issues

A number of critical decisions and methodological choices were made during this thesis. Developing a farm model especially for Ethiopia where there has been literally no research on the subject is a challenge by itself and requires a number of decisions.

6.1.1 Model re-usability and representation

By definition, models are abstractions of reality and consequently they cannot include all factors that influence a certain phenomenon. Some variables that may impact crop production and overall efficiency were not included in the model for various reasons. For instance, the profile of farmers in terms of their level of education, access to key agricultural information and consultation can impact farmer effectiveness. This may add another perspective to the model that can make it more comprehensive.

On the other hand, the model developed in this thesis is customized for the region of Jimma. But it doesn't represent a specific agronomic condition. The annual rainfall, the soil type, the humidity and the altitude for which data was collected does not reflect a particular agronomic and topographic conditions. The model was created for an average rainfall, soil fertility, temperature and altitude in the region. This has both advantages and disadvantages. On the advantage side, it has a broad appeal of representing many regions in Ethiopia that have the topographic and agronomic condition within the limits of Jimma region. But it can serve as a basic framework for future models. Future researchers can exclude or include crops, change yields, increase or decrease labor demand and other variables and can still follow the model structure to a great extent.

6.1.2 Crop rotation scheme

Determining the share of the three crop families was a difficult task due to two reasons. First, Ethiopian farmers are in general unfamiliar with oilseed crops and including oilseeds in the cropping plan further complicated how land should be allocated. Secondly, the major rotation practice in Ethiopia is rotating cereals with pulses and even sometimes, cereals with cereals. It is easy to infer that cereals should consume a larger part of the land, but how much to assign was only settled after consulting plant researchers at PRI Wageningen University (Wijnands et al, 2011). With the oilseeds in the picture as a new crop family to be introduced, the crop rotation scheme remains ambiguous and more complex. That is why the thesis needed a crop rotation rule that handles these three crop families in a well-structured scientific manner.

Conducting a field research and interviewing the farmers would have helped to adopt a more representative and flexible crop rotation rules, but doing so would not result in a fundamentally different rotation scheme crafted in the model. The model assigned a maximum of 67% of the land to the cereals and the rest is left for either pulses or oilseeds. Individual cereals can grow on a maximum share of 50% of the total land under cultivation while individual pulses and oilseeds can claim up to 25% of the land. Even if 67% is a big share by any measure, surprisingly it is not sufficient when compared with the reliance of Ethiopian farmers on cereals. As noted, farmers of Jimma region on average grow cereals over 80% of their farm land.

The model delicately handled the three crop families in a way it is in parallel with the actual farm practice and in a way the rotation sequence preserves soil fertility and enhance crop yields. Hence, the actual farm practice, soil fertility and crop yields were balanced while formulating the crop rotation rules adopted in the model. As a result, the crop rotation rules of the model are not purely the same with the scientific recommendations and yet they are not perfectly similar to the actual rotation practices of farmers in Ethiopia. Table 20 below reviews model results by excluding oilseeds and assigning all the land to either cereals or pulses to make it closer to the actual farm practice.

Table 20 Results of other rotation rules at farm size of 5 hectares

Crop	Base	Rotation rule X*	Rotation rule Y*
Cereals	**3.334**	**5.000**	**5.000**
Teff	0.258	0.295	0.258
Wheat	0.431	2.000	0.067
Sorghum	0.145	0.145	0.145
Maize	2.500	2.500	4.531
Pulses	**0.061**	**0.000**	**0.000**
Faba beans	0.043	0.000	0.000
Field pea	0.018	0.000	0.000
Oilseeds	**1.606**	**0.000**	**0.000**
Soya	0.656	0.000	0.000
Noug	0.000	0.000	0.000
Linseed	0.000	0.000	0.000
Sunflower	0.000	0.000	0.000
Sesame	0.950	0.000	0.000
Gross farm income	23, 457	24, 587	25,612
Crop Sales	24, 851	27, 069	28,103
Total Expense	1,394	2482	2491
Food Expense	102	376	376
Fertilizer Expense	1,199	1706	1832
Interest Expense	14	96	121
Labor Expense	79	305	162
Seed Expense	0	0	0

*****_Rotation rule X: Oilseed crops are excluded from the rotation while keeping rotation rules limiting the maximum share of individual crops. But there is no limit on crop families (cereals, pulses and oilseeds)_

**Rotation rule Y: Oilseed crops are excluded from the rotation without any other rotation rules*

As it is shown avoiding oilseed crops from rotation since they are new crops to Ethiopian farmers has a positive impact on gross farm income as it increased through those transitions. But these spike in the gross farm income are not sustainable and are not as positive as they seem. The biggest problem with these kind of rotations is their detrimental effect of soil fertility and crop yield. Following the cropping plan indicated in the last two columns may give a farmer such a high gross farm income on the first time tilling or in the first season. But rotating within the same crop family and growing a single crop (maize) over such a huge share of land will harm the soil and the crop yields will continuously decline. Thus, the observed gross farm income cannot be kept at the same level or increased.

6.1.3 Assumptions made in the thesis

There are substantial alternatives to some assumptions made in developing the model. The major ones that deserve critiques are the ones made with regard to labor and land. As far as labor goes, there was an assumption that kept the model simple and more efficient. That is the constant wage rate assumed in hiring labor. For all farm activities , the cost of hiring was considered constant despite the fact that some farm functions require slightly more skills than others. This, not only made the handling of labor simple, but also avoided the arduous task of setting up a mechanism to trace which farm activities are hired in which period and assigning a different wage rate to each activity. Even if customizing the rate of hiring to different farm activities will make the model far more complicated, it is sometimes that can potentially better the model. The main concern in going through that road is the costs of setting up that mechanism may out weight the benefits of performing it.

Despite this, however, the model adopted a very robust way of handling the labor supply. The model deserves much credit for dissecting a single farming season in to 26 periods on a 2 weeks basis and assign different levels of labor supply to each period depending on labor mobility and seasonal migrations that affect the labor supply. The flexibility enjoyed by this mechanism made it easy to account labor additions as a result of labor of the students of the family available during school breaks. The only weakness in this regard is the failure of the model in considering labor supply additions resulting from labor migrations that are becoming prominent in Ethiopian agriculture. During farm peak seasons harvesting, there is a considerable migration of labor from North Ethiopia to South.

The migration occurs for two reasons. Firstly, the harvest season involves the hottest three months in Ethiopia in general. But in the north, the temperature is quite extreme and there is a tendency of labor force shift to pass the time in the south. So, this creates more labor in southern areas like Jimma region. Secondly, harvest season is quite labor demanding and beside that, some farmers want to avoid risk of crop catastrophes from unexpected rains. Hence, there is an urgency to perform harvesting on time to avoid the negative effects of a possible rainfall. This labor demand provides an opportunity for young labor in the North, where the lands are not so fertile to grow crops, to move south and earn some money.

But money is not the only vehicle through which these transactions are made between the migrants and the farming labor. In fact, the more frequently practiced exchange is in terms of sharing the crop yields collected at the end of the farming season. Farmers do so to avoid cash expense since financial liquidity is one of the major bottlenecks constantly faced in Ethiopia. There is no standard share on how the yield is shared, which was one of the major reasons why labor migration effect was ignored by the model. Yield exchanges usually take place through an oral dialogue between a migrant and a farmer, thereby making it difficult to adjust the crop yields.

As far as land is concerned, the model assumed that each hectare of the land can be used for growing crops. Fallows are allowed in the model, but they won't have a role in the results observed in the previous chapter, resulting from the process of optimization. Farmers may flexibly preserve some part their land for grazing and even may rent out some pieces of land to other farmers. The possibility of renting out is not particularly considered. There is an extremely limited information on land renting to include it in the model on the one hand. But on the other hand, including the possibility can potentially influence the results extracted from the model.

6.2 General discussion of results

To test the validity of the model, the results of actual and optimal cropping plans were compared. There is a considerable proximity in the financial outcomes of both plans. Nevertheless, it doesn't guarantee a good representative model. A net difference of more than 600 birr was observed between the two plans, in which the optimal plan recorded a higher gross farm income. This indicates the actual crop growing plan doesn't represent the best possible scheme to maximize the gross farm income.

Food requirement has proven to be the most critical item in shaping the optimal cropping plans. It also shapes the crop rotation schemes indirectly. Cereals take a significant role in Ethiopian food security. This creates a natural demand of growing these crops more than other crop families. The demand in turn drives the price of the cereals up giving them a considerable advantage of a higher chance of being included in the optimal plan. Accordingly, in both the conventional and best farm practices, cereals (teff, wheat, sorghum and maize) consumed most of the land allowed. In all farm sizes, cereals did consume 67% of the land, which is the maximum allowed share of the land for the crop family. Except for the 1 hectare plan under the conventional farm practice, maize utilized nearly 50% of the land. Maize's high yield, high gross margin and its relatively lower labor consumption were the major reasons for its inclusion in the optimal results. The prospect of maize is even brighter when the demand for the crop as a food source and its new role as an energy source (ethanol) is considered.

Apart from the land share of cereals in the optimal cropping plan, the role of pulses(faba and field peas) and oilseeds (soya, noug, linseed, sunflower and sesame) are more or less the same under both the conventional and best farm practices. Pulses were mostly grown over the minimum land required to meet the food demand. Soya bean and sesame were the only two oilseed crops that managed to be in the optimal plan despite the fact that noug and linseed were more critical for food security. Noug and linseed were purchased from the external market to meet the food demand rather than growing them, which was found to be preferable to maximize the gross farm income.

Hence, in general, at normal conditions of conventional and best farm practices, soya beans and sesame are in the optimal cropping plan, but their significance comes second to the cereals. Even if their share is marginal, their contribution in the optimal plan also has a good prospect like maize. There are efforts by food security advocacy groups to enable Ethiopian farmers to diversify their food sources. This is a good policy and also beneficial to the farmers. These efforts can potentially divert the enormous dependence on cereals for food to oilseeds. The extra demand created will cause a rise in price of oilseeds. This will in turn make the gross farm income of oilseeds more attractive and increases the level of their involvement in the optimum cropping plan.

A significant difference between the optimal results of conventional and best farm practices is recognized when the effect of constraints is assessed through sensitivity analysis. Under best farm practices, limiting credit facilities has proven to have a far more negative impact. When the credit level is set at less than 1000 birr per hectare , there will be a fallow land in the 5 hectare and larger crop plans. Fallow lands (unutilized pieces of farm land) significantly decrease crop sales from yields and ultimately causing a sharp decline in the gross farm income. Land becomes not binding for the first time throughout the analysis of model results when credit is fixed at low levels. In relation to this, the cash need under the best farm practices was higher than the conventional farm practices, which was why credit limitation had such a huge negative impact.

In assessing the prospect of oilseeds through price rises, the participation of soya bean in the optimal cropping plan can be doubled with a slight increase of 0.5 birr/kg in its price. The price of sunflower has to be increased by 3 birr to be included in the optimal plan, which is a big ask. Even by then, its contribution is marginal.

The impact of labor was not as big as anticipated, which was demonstrated by the marginal negative impact of unfavorable labor conditions on the gross farm income. Under conventional farm practices, labor becomes binding only for 5 hectares and larger farm sizes. And oxen labor becomes binding before human labor. But it is human labor that becomes binding before an oxen labor under best farm practices. The demand of human labor under best farm practices is higher than oxen labor due to the extra human intervention needed to delicately handle the crops and vice versa under the conventional farm practices.

6.3 Conclusions from results

The major conclusions from the thesis are:

1. The model developed in this thesis is a flexible and reasonably a sound representative of the actual farm practice in the region. There are some drawbacks, if dealt with would make the model more representative at the cost of making it more complex. Nevertheless, considering the fact there were no significant past works in farm modeling of Ethiopia, the model can be regarded as a good start. The difference of 600 birr (around 11% above the actual plan) between the income of the optimal and the actual cropping plan indicates that the model is not that far away from the farm reality. On the other hand, the model introduced relatively new crops (Oilseeds) to a typical farm and induced greater competition within crops for limited resources. The new crops were fit to the actual farm situation effectively so that food security and financial demands of the farmers were met. But as a future recommendation, farm research institutes in Ethiopia should actively take on farm modeling for better understanding of crop production on Ethiopian farms.

2. The optimal crop plan of the model yielded a greater financial outcome than the actual cropping plan adopted from the CSA data. The deciding factor in gross farm income improvement from the optimal results was how the land that is left over from cereal crops was utilized. In actual farm practice, pulses(faba and field pea) and some oilseed crops(noug and linseed) were grown along the cereals. These crops were not attractive financially and instead of them, soya bean and sesame were included in the optimal plan. These crops had a positive impact on the gross farm income. Hence, there is room for improving farmers income and sustain crop yields at a desired level through further research in farm modeling and better land distribution among the crops.

3. Food requirement played a critical role in establishing a framework in how the land is distributed in the optimal cropping plans. In general, crops that are an important source of food security have higher prices, giving those crops an edge to be included in the optimal results. Cereals, with a leading role of maize (50% of the land mostly), took a great role in most of the cropping plans. Soya beans and sunflower are the two oil seed crops that covered most of the land left over from the cereals. Pulses were grown on the minimum land required to meet the food demand.
4. Increasing the price of soya bean by a slight 0.5 birr/kg increases its share in the cropping plan by a significant proportion, but the price of sunflower has to rise monumentally to have a considerable role in the optimal results.

5. The optimal results of the conventional and best farm practices more or less have the same nature. However visible differences arise when the role of the constraints were assessed. Land was found to be binding in all cases except the case of low credit facilities under the best farm practices. Low credits resulted in unused land under best farm practices hugely impacting the gross farm

income. For that reason, credit providers (banks and the government) should make sure that farmers under best farm practice preserve sufficient level liquidity. Oxen labor is scarcer than human labor while human labor takes that role under the best farm practices. Thus, conventional practice farmers should put forward a continuous effort in rescheduling oxen labor and minimizing oxen hiring as much as possible. The same implication can be made for the best practice farmers with regard to the human labor

6.4 Recommendations for future researches

The research presented in this thesis leads to a number of new, interesting and relevant research topics. There are also ways to improve the model in this thesis. The model can be made more comprehensive by adding other factors that can possibly influence the gross farm income and the decision making process of farmers. These factors can be the effect of farm cooperatives, farmer's level of education and access to information. Many of the modeling decisions in this thesis were kept straight forward, flexible and simple due to lack of past works and data limitations. The model can be made more challenging and robust by setting up various mechanisms to further make it more flexible. One of this adjustment can be expanding options of labor and creating a set up through which variable rate of hiring is possible.

It has been indicated also that the model doesn't represent a perfectly specific agronomic and topographic condition since most of the general information about the agricultural environment were based on an average basis. It is recommended for the future a farm model be developed for a specific soil type, rainfall amount and weather condition so that a more direct interpretation of model results for specific regions and individual farmers can be made. Detailed regional or farm specific data bases can be used for creating such models. Economic analysis such as marginal analysis of various factors, credit-fertilizer correlation and other correlations can further enrich the comprehensiveness of this research.

Formulating crop rotation rules was a difficult task in developing this model. To improve model performance in this regard, farm observation and field research is recommended for the future. Finally, GAMS software has been very helpful in conducting this thesis. But other open source software like JAVA or R can be used for optimization with a greater detail and complexity.

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Appendices:

Appendix 1:Man labor hours

General activity man hours- conventional farming and best farm practices

General Activity		Crops										
	Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Land Preparation	Period 1			12	12	12	12					
	Period 2							12			12	
	Period 3	12	12						12	12		12
	Period 4											
	Period 5											
	Period 6											
	Period 7											
	Period 8											
	Period 9											
	Period 10											
	Period 1 1											
	Period 12											
	Period 13											
Transport and Storage	Period 14											
	Period 15				24							
	Period 16											
	Period 17		16		8							
	Period 18	8	28			8	8		4			
	Period 19	8				24	24	16	4	4	8	16
	Period 20							16		4	16	
	Period 21			16								
	Period 22			16								
Manure Application	Period 23	4	4	4	4	4	4	4	4	4	4	4
	Period 24	4	4	4	4	4	4	4	4	4	4	4
	Period 25	4	4	4	4	4	4	4	4	4	4	4
	Period 26	4	4	4	4	4	4	4	4	4	4	4

Man hours for tilling under conventional farming

Tillage by ox	Crops										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1			32								
Period 2				32							
Period 3			32		32	32					
Period 4			16	32			32				32
Period 5		32			32	32		32	32	32	
Period 6	64	48		16			32				32
Period 7	80	32			16	16	16	48	48	32	
Period 8	32							16	16	16	16
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14											
Period 15											
Period 16											
Period 17											
Period 18											
Period 19											
Period 20											
Period 21											
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Man hours for tilling under best farm practices

Tillage by ox	**Crops**										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1			32								
Period 2				32							
Period 3			32		32	32					
Period 4			32	32			32				32
Period 5		32			32	32		32	32	32	
Period 6	64	48		32			32				32
Period 7	80	64			32	32	32	48	48	32	
Period 8	64							32	32	32	32
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14											
Period 15											
Period 16											
Period 17											
Period 18											
Period 19											
Period 20											
Period 21											
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Man hours for Sowing-Weeding under conventional farming

Sowing-weeding		Crops										
	Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
	Period 1											
	Period 2											
	Period 3											
Sowing	Period 4			24								
	Period 5											
	Period 6				16			24				
	Period 7	40	24			16	16		32	40	16	
Weeding	Period 8			32								16
	Period 9		48		32			32			32	
	Period 10	32				48			32	48	8	
	Period 1 1			32	36		32	32				32
	Period 12	16	48				16	48	24	32		
	Period 13					48						16
	Period 14											
	Period 15											
	Period 16											
	Period 17											
	Period 18											
	Period 19											
	Period 20											
	Period 21											
	Period 22											
	Period 23											
	Period 24											
	Period 25											
	Period 26											

Man hours for Sowing-Weeding under best farm practices

	Sowing-weeding	**Crops**										
	Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Sowing	Period 1											
	Period 2											
	Period 3											
	Period 4			48								
	Period 5											
	Period 6				32			48				
	Period 7	48	48			32	32		48	64	32	
Weeding	Period 8			32								32
	Period 9		48		32			32			32	
	Period 10	32				48			32	48	8	
	Period 1 1			16	20		16	32				16
	Period 12						8	16	8	8		
	Period 13					24						8
	Period 14											
	Period 15											
	Period 16											
	Period 17											
	Period 18											
	Period 19											
	Period 20											
	Period 21											
	Period 22											
	Period 23											
	Period 24											
	Period 25											
	Period 26											

Man hours for activities from harvesting, threshing and cleaning under conventional farming

(Each crop has two labor figures under this activities. The first one corresponds to harvesting. The second one relates to both threshing and cleaning)

Harvest, threshing cleaning	**Crops**										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1											
Period 2											
Period 3											
Period 4											
Period 5											
Period 6											
Period 7											
Period 8											
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14				64							
Period 15		128		24		96					96
Period 16	160				96		112				
Period 17		48						104	112	96	
Period 18	48				40	48		24			8
Period 19			104								
Period 20							48		40	30	
Period 21											
Period 22			40								
Period 23											
Period 24											
Period 25											
Period 26											

Man hours for activities from harvesting, threshing and cleaning under best farm practices

(Each crop has two labor figures under this activities. The first one corresponds to harvesting. The second one relates to both threshing and cleaning)

harvest-cleaning	**Crops**										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1											
Period 2											
Period 3											
Period 4											
Period 5											
Period 6											
Period 7											
Period 8											
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14				128							
Period 15		192		72		144					144
Period 16	240				192		168				
Period 17		96						156	168	144	
Period 18	132				64	48		96			32
Period 19			156				96			60	
Period 20									96	16	
Period 21			96								
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Appendix 2: Oxen labor hours

Oxen hours for tilling under conventional farming

Tilling	**Crops**										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1			64								
Period 2				64							
Period 3			64		64	64					
Period 4			32	64			64				64
Period 5		64			64	64		64	64	64	
Period 6	128	96		32			64				64
Period 7	160	64			32	32	32	96	96	64	
Period 8	64							32	32	32	32
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14											
Period 15											
Period 16											
Period 17											
Period 18											
Period 19											
Period 20											
Period 21											
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Oxen hours for tilling under best farm practices

Tilling	**Crops**										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1			64								
Period 2				64							
Period 3			64		64	64					
Period 4			64	64			64				64
Period 5		64			64	64		64	64	64	
Period 6	128	96		64			64				64
Period 7	160	128			64	64	64	96	96	64	
Period 8	128							64	64	32	64
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14											
Period 15											
Period 16											
Period 17											
Period 18											
Period 19											
Period 20											
Period 21											
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Oxen hours for threshing under conventional farming

harvest cleaning	**Crops**									
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1											
Period 2											
Period 3											
Period 4											
Period 5											
Period 6											
Period 7											
Period 8											
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14											
Period 15											
Period 16											
Period 17		96									
Period 18	96							48			
Period 19											
Period 20										32	
Period 21			40								
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Oxen hours for threshing under best farm practices

harvest cleaning	**Crops**										
Time	Teff	Wheat	Sorghum	maize	fava	fieldp	Soybean	neug	linseed	sunflower	Sesame
Period 1											
Period 2											
Period 3											
Period 4											
Period 5											
Period 6											
Period 7											
Period 8											
Period 9											
Period 10											
Period 1 1											
Period 12											
Period 13											
Period 14											
Period 15											
Period 16											
Period 17		192									
Period 18	192							96			
Period 19											
Period 20										64	
Period 21			192								
Period 22											
Period 23											
Period 24											
Period 25											
Period 26											

Appendix 3: Production and utilization

Crop Production and consumption in Ethiopia and Jimma

Region	Crop	Production	Consumption	Seed	Sale	Wages	Feed	Other
	Ton	%	%	%	%	%	%	%
Ethiopia	Cereals	144,964,059	66	16	14	1.3	0.6	3.0
	Pulses	19,646,301	61	21	15	0.8	0.3	1.9
	Oilseeds	6,556,044	53	12	29	1.3	0.1	4.6
	Neug	1,906,523	24	13	60	1.3	0.1	1.2
	Linseed	1,560,693	46	15	35	0.6	0.1	1.4
	Sesame	2,166,406	19	10	68	2.4	0.1	0.6
	Rapeseed	386,636	43	11	44	0.3	0.1	0.8
Jimma	Cereals	6,299,960	60	13	11	3.3	0.3	2.6
	Pulses	386,698	69	13	16	1.1	0.0	0.9
	Oilseeds	89,196	53	12	29	1.3	0.1	4.6
	Neug	50,632	32	15	51	0.1		0.9
	Linseed	19,669	65	13	18	2.8		0.9
	Sesame	12,066	40	4	55			0.5
	Rapeseed	1,348	65	9	25		0.5	0.3

Appendix 4: Fertilizer and seed input

Fertilizer (individual nutrient required per hectare to facilitate crop growth)

	Conventional farming			Best farm practices		
	N	P	K	N	P	K
Unit Crops	kg	kg	kg	kg	kg	kg
teff	21.3	4.3	4.3	38.3	7.7	7.7
wheat	21.9	3.5	4.1	56.9	9.1	10.7
maize	15.0	2.1	3.2	60.2	8.4	12.8
sorghum	18.0	2.9	3.5	45.0	7.3	8.8
faba	42.0	4.2	10.6	105.0	10.5	26.5
fieldpea	36.0	4.6	10.4	74.0	9.2	20.8
soya	58.0	6.1	18.0	139.2	17.0	43.1
noug	29.0	6.0	6.0	23.2	5.6	5.6
linseed	31.2	5.0	8.1	28.1	4.5	7.3
sunflower	31.6	6.3	6.1	44.3	8.8	8.6
sesame	28.4	6.0	4.4	45.4	9.6	7.1

Source: Prota database and USDA (2010)

Seed amount required

	Conventional farming	Best farm practices
unit	Kg/hectare	Kg/hectare
Crops	Seed rate	Seed rate
teff	30	30
wheat	150	150
maize	30	30
sorghum	15	15
faba	185	185
fieldpea	125	125
soya	50	50
noug	15	15
linseed	35	35
sunflower	15	15
sesame	15	15

Appendix 5: Crop rotation table

Crop coefficients of the crop rotation rules

Constraint	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*	*C11*	*Fallow*	*RHS*
land	1	1		1	1	1	1	1	1	1	1	1	<= Rb
CR1	2	0	0	0	0	0	0	0	0	0	0	0	</>= Rb
CR2	0	2	0	0	0	0	0	0	0	0	0	0	</>= Rb
CR3	0	0	2	0	0	0	0	0	0	0	0	0	</>= Rb
CR4	0	0	0	2	0	0	0	0	0	0	0	0	</>= Rb
CR5	1	1	1	1	-2	-2	-2	-2	-2	-2	-2	-2	</>= Rb
CR6	1.5	1.5	1.5	1.5	0	0	0	0	0	0	0	0	</>= Rb
CR7	0	0	0	0	4	4	4	0	0	0	0	0	</>= Rb
CR8	0	0	0	0	0	0	0	4	0	4	0	0	</>= Rb
CR9	0	0	0	0	0	0	0	0	2	0	0	0	</>= Rb
CR10	-1	-1	-1	-1	0	0	0	0	-1	3	0	-1	</>= Rb
CR11	-1	-1	-1	-1	-1	-1	-1	3	-1	0	0	-1	</>= Rb
CR12	0	0	0	0	0	0	0	4		4	0	0	</>= Rb
CR13	0	0	0	0	0	0	0	0	0	0	4	0	</>= Rb

Note:
C1-C11 represents the crops
Rb=Available farm size in hectares

Appendix 6: Costs (Inputs, hiring and food) in ETB

Activity	unit	Costs
Hiring man labor	1 hour	1.25
Hiring oxen labor	1 hour	0.75
Tilling by tractor	1 ha	500
Seedbed preparation by tractor	1 ha	250
Sowing by tractor	1 ha	500
Weeding by tractor	1 ha	75
Harvest, threshing and cleaning by combine harvester	1 ha	1700
Urea	1 Kg	2.50
DAP	1 Kg	2.55
Interest on credit	1 ETB	0.1