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The Effect of Policy Incentives and Technology on Sustainable Land Management and Income of Small Farm Households:

A Bioeconomic Model for Anjeni Area, North Western Ethiopia

Cuvillier Verlag Göttingen
Internationaler wissenschaftlicher Fachverlag

CENTER FOR DEVELOPMENT RESEARCH (ZEF)
DEPARTMENT OF ECONOMIC AND TECHNOLOGICAL CHANGE

THE EFFECT OF POLICY INCENTIVES AND TECHNOLOGY ON SUSTAINABLE LAND MANAGEMENT AND INCOME OF SMALL FARM HOUSEHOLDS: A BIOECONOMIC MODEL FOR ANJENI AREA, NORTH WESTERN ETHIOPIA

Inaugural - Dissertation
Zur
Erlangung Des Grades

Doktor der Agrarwissenschaften
(Dr.agr.)

der
Hohen Landwirtschaftlichen Fakultät
der
Rheinischen Friedrich - Wilhelms - Universität
zu Bonn

Vorgelegt am 11 October 2010
von
Yitayal Anley Mengistu
aus
Äthiopien

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.
1. Aufl. - Göttingen : Cuvillier, 2011
Zugl.: Bonn, Univ., Diss., 2010

978-3-86955-623-9

Printed with support of Deutscher Akademischer Austauschdienst (DAAD)

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Nonnenstieg 8, 37075 Göttingen
Telefon: 0551-54724-0
Telefax: 0551-54724-21
www.cuvillier.de

1. Auflage, 2011
Gedruckt auf säurefreiem Papier

978-3-86955-623-9

Dedication

To my late brother, Sinamaw Anley Mengistu. May his soul rest in peace!

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List of Acronyms

ACSI	Amhara Credit and Saving Institute
ADLI	Agricultural Development Led Industrialization
CACC	Central Agricultural Census Commission
CDF	Cumulative distribution function
CGE	Computable General Equilibrium
CPPs	Comprehensive Package Programmes
CSA	Central Statistical Authority
DAAD	Deutscher Akademischer Austauschdienst
DAP	Di-ammonium phosphate
EEA	Ethiopian Economic Association
FAO	Food and Agriculture Organization of the United Nations
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GTZ	*Gesellschaft für Technische Zusammenarbeit*
HYV	High yielding variety
ILRI	International livestock Research Institute
LP	Linear programming
LPM	Lower partial moment
MFIs	Micro Finance Institutions
MoARD	Ministry of Agriculture and Rural Development
MPPs	Minimum Package Programmes
NUTMON	Nutrient Monitoring Model
PADEPs	Peasant Agricultural Development Programmes
PADETES	Participatory Agricultural Demonstration Training and Extension System
PDF	Probability density function
PMP	Positive mathematical programming
SCRP	Soil Conservation Research programme
TLU	Tropical livestock unit
USLE	Universal soil loss equation
ZEF	Zentrum für Entwicklungsforschung (Center for Development Research)

ACKNOWLEDGEMENT

I would like to express my gratitude to all individuals and institutions who contributed, in one way or another, to the successful completion of my study. First and foremost, I would like to express my deepest gratitude to my research supervisors, Prof. Dr. Ernst Berg and Prof. Dr. Klaus Frohberg. Prof. Dr. Ernst Berg provided me meticulous guidance, insightful comments and suggestions during the course of my study period. I enjoyed his hospitality and guidance in a friendly and free atmosphere. I am equally indebted to Prof. Dr. Klaus Frohberg for his constructive comments, insights and suggestions during the early stage of my study. He devoted considerable time and energy to broaden and shape my understanding of economic modelling. I thank both of them very much. I also thank my tutor Dr. Victor Safari for providing me constructive comments and suggestions at the beginning of my study period.

My thanks and sincere appreciation goes to Mrs. Rosemarie Zabel and Dr. Günther Manske for their unreserved effort to support and facilitate my study at the Center for Development Research (ZEF). Their efficient administrative services, the friendly working environment and the excellent educational facilities at ZEF made my life very simple and enjoyable. I am very grateful to the German Academic Exchange Service (*Deutscher Akademischer Austauschdienst* (*DAAD*)), The German Federal Ministry of Education and Research (*Bundesministerium für Bildung und Forschung*) and the German Technical Cooperation *(Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ))* for providing me generous financial support for my study and research.

I extend my gratitude to Jimma University for providing me a study leave and administrative support during my field work. I am also grateful to the Ethiopian Ministry of Agriculture, Addis Ababa University and the International livestock Research Institute (ILRI) for allowing me full access to their respective libraries. I would like to thank Dr. Gete Zeleke for providing me the Soil Conservation Research Project data for Anjeni area. I thank the staff of Dembecha district department of Agriculture for their willingness and support of my study during data collection. Especially, I would like to thank Leyikun Berihanu, Mengistu Desalegne, Lubaba Abdela, Abebaw Aderaw, Mezigebu Taye, Linger Anley, Getnet Enyew, Yeneneh Berhanu, Yared Alazar and Nitsuh Getaneh for their unreserved effort in collecting the primary data. My heart felt thanks also goes to farmers in Anjeni area for their genuine cooperation and sacrificing their precious time during interview, field measurement and group discussions. I would like to extend my appreciation to Endaweke Wondim for assisting me in data entry and data cleaning.

I would like to thank Dr. Seid Nuru and Dr. Daniel Tsegaye for providing me continuous encouragement and useful advises. I am grateful to my class mates Julia Kloos, Teresa Linz, Edward Amponash, and Patricia Aidam for the good time we had together during our course work at ZEF. Especially, I would like to extend my heartfelt thanks to Julia Kloos for spending her precious time to translate the thesis abstract to German. I am highly grateful to my dear friend, Fasil Banti, for the good time we spent together in Bonn and for the important discussions we had. My stay in the clean and beautiful city of Bonn was inspiring and the excellent public services along with the disciplined and wise people of Bonn helped me develop and transform my perception beyond my expectations.

Last but not least, I would like to express my heart-felt gratitude to my father Anley Mengistu, my mother Ayehu Belay and my brother Belachew Anley for their love and encouragement since my childhood and offering the opportunity of education they never had. My dream wouldn't have been realized without the strength, love and support of my wise and visionary mother. Thank you very much!

ABSTRACT

Land degradation due to soil erosion and soil nutrient depletion has contributed to declining agricultural productivity, poverty and food insecurity in Ethiopia. Due to the continuous dependency on agriculture, land degradation and unfavorable climatic conditions, rural development policies in Ethiopia are challenged by two important issues: the need to improve household income to meet the demand for food in the face of growing population and the need to improve or sustain the productivity of land. This highlights the important task of undertaking development research to understand and design appropriate policy incentives and technology interventions.

Using primary and secondary data, this study employed a bioeconomic model in a mathematical programming framework to analyze the impact of selected policy incentives and technology interventions on land quality and income of small farm households and an econometric model to assess the factors that influence the use of improved soil and water conservation measures in Anjeni area, North Western Ethiopia.

Analyses of the results of the bioeconomic model indicate that there are potentials for policy incentives and technology interventions to improve household income and reduce land degradation. Most scenarios considered in the model increase income of farm households. However, the results indicate that the process of land degradation can’t be reversed and these interventions are not able to fully control land degradation, they can only slow down the process of land degradation.

The combined effect of improved soil and water conservation measures, access to fertilizer credit and high yielding crop variety appear to have the highest impact on income and land degradation as compared to the effect of individual policy incentives and technology interventions as they address, simultaneously, several constraints of small farm households. However, these policy incentives and technology interventions can’t, simultaneously, increase income and reduce land degradation. A conclusion that can be drawn from this analysis is that the use of physical soil conservation measures alone may not be a sufficient solution to curb the problem of land degradation and other

alternatives, such as biological soil conservation measures, should be thought of as an integral part of the solution to the problem of land degradation.

Finally, analysis of the results of the econometric model indicated that the probability and extent of use of improved soil and water conservation technologies largely depends on the resource constraints such as size of farm land and labour and the capacity and level of understanding of farm households such as education level, age and perception about the problem of land degradation. This suggests that Interventions and agricultural development programs that seek to address farmers' resource constraints and that provide incentives to farm households have a positive and significant effect on promoting soil and water conservation measures and sustaining agricultural productivity and food security.

KURZFASSUNG

Die zunehmende Degradierung von Böden durch Erosion und Verarmung an Nährstoffen hat zu einer abnehmenden landwirtschaftlichen Produktivität, Armut und Nahrungsmittelunsicherheit in Äthiopien geführt. Die fortwährenden Abhängigkeit von der Landwirtschaft trotz dieser Probleme und hinzukommenden ungünstigen Klimabedingungen erfordert Politikmaßnahmen, die zwei wichtige Aufgaben erfüllen: zum einen die Einkommen der Haushalte zu erhöhen um die Nachfrage nach Lebensmitteln bei wachsender Bevölkerung sicher stellen zu können und zum anderen die Produktivität des Bodens zu verbessern bzw. zu erhalten. In Anbetracht dieser Aufgaben, ist es ein wichtiger Schritt, Entwicklungsforschung zu betreiben um Zusammenhänge zu verstehen und darauf aufbauend, angemessene Politikanreize und entsprechende Technologie-Interventionen ermitteln zu können.

In dieser Studie wird ein bio-ökonomisches Modell basierend auf mathematischer Programmierung mit Primär- und Sekundärdaten erstellt, um den Einfluss ausgewählter Politikanreize und Technologie-Interventionen auf Landqualität und Einkommen kleinbäuerlicher Haushalte hin zu analysieren. Ein ökonometrisches Modell wurde geschätzt um die Faktoren zu identifizieren, die die Anwendung von Maßnahmen zur Boden- und Wasserkonservierung beeinflussen. Beide Modelle beziehen sich hierbei auf die Anjeni- Region im Nordwesten Äthiopiens.

Die Ergebnisse des bio-ökonomischen Modells zeigen, dass es Möglichkeiten gibt, mit Hilfe von Politikanreizen und Technologie-Interventionen verbesserte Haushaltseinkommen und verringerte Landdegradierung herbeizuführen. Meisten Szenarien im Modell steigerten die Einkommen landwirtschaftlicher Haushalte. In Bezug auf die Bodendegradierung zeigen die Ergebnisse jedoch, dass diese nicht vollständige aufgehoben, sondern nur verringert werden kann.

Werden verbesserte Boden- und Wasserkonservierungsmaßnahmen mit Zugang zu Düngemittelkrediten und Hochleistungsfeldfrüchten kombiniert, zeigen sich die größten Effekte auf Einkommen und Landdegradierung verglichen mit denen einzelnen Maßnahmen, da diese simultan auf mehrere Einschränkungen landwirtschaftlicher

Haushalte wirken. Politikanreize und Technologie-Interventionen können jedoch nicht gleichzeitig Haushaltseinkommen erhöhen und Landdegradierung reduzieren. Eine Schlussfolgerung dieser Ergebnisse ist, dass physikalische Bodenkonservierungsmaßnahmen nicht als alleinige Lösung für das Problem der Bodendegradierung dienen können, sondern weitere Maßnahmen wie z.B. biologische Bodenkonservierungsmaßnahmen hinzugezogen werden sollten.

Die Analyse des ökonometrischen Models zeigte, dass die Wahrscheinlichkeit und das Ausmaß der Nutzung verbesserter Boden- und Wasserkonservierungsmaßnahmen zu einem großen Teil von Faktoren wie verfügbarer landwirtschaftlicher Fläche und Arbeitskräfte sowie Bildungsstand, Alter und Wahrnehmung des Schwere der Bodendegradierung abhängt. Dieses Ergebnis zeigt, dass Interventionen und landwirtschaftliche Entwicklungsprogramme, die auf die Verfügbarkeit von Ressourcen abzielen und Anreize für landwirtschaftliche Haushalte schaffen, einen positiven und signifikanten Einfluss auf die Anwendung von Boden- und Wasserkonservierungsmaßnahmen und den Erhalt landwirtschaftlicher Produktivität und Nahrungsmittelsicherheit haben.

CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture is the most important economic sector in Ethiopia. It provides about 44% of the GDP, 80% of the export revenue and 80% of employment opportunity (NBE, 2006). Despite its importance, the sector is characterized by low level of production and productivity and dominated by traditional methods of crop and livestock production systems (Tefera *et al*., 2000).

One of the major problems threatening the productivity of agricultural land is land degradation in the form of soil erosion and soil nutrient depletion. Land degradation has contributed to declining agricultural productivity, poverty and food insecurity in the high lands of Ethiopia. High rate of population growth on one hand and declining productivity of agricultural land on the other hand are widening the gap between food supply and food demand and threatening the livelihood of small scale subsistent farmers (Gebremedihn and Swinton, 2003).

The introduction and promotion of improved soil and water conservation measures in Ethiopia started in the 1980s and 1990s. However, the process of human-induced land degradation is a long phenomenon and its causes are deeply rooted in its geography, agro-climatic factors, socioeconomic conditions and political history. Limited use of improved soil and water conservation measures, high cost of and limited access to agricultural inputs such as fertilizer and credit to replenish lost nutrients, continuous cropping on slopping and marginal lands and other socio economic conditions deprived the farmers of incentives to improve land management and their livelihood, while misguided development policies, population pressure, fragmented land holdings and insecure land tenure are considered to be the underlying causes of land degradation (Shiferaw and Holden, 1998; Bogale, 2002; Tefera *et al*., 2000; Gebremedihn and Swinton, 2003).

Deforestation and continuous cropping on sloping and marginal lands without suitable soil and water conservation technologies and amendments to replenish lost nutrients has led to wide spread soil erosion and soil nutrient depletion in most Ethiopian highlands (FAO, 1986; Bogale, 2002). The average rate of soil erosion has been estimated to be about 42 tons per hectare per year on cultivated fields (Hurni, 1988). Serious soil erosion is estimated to have affected 25 percent of the area of the highlands to the extent that they will not be economically productive in the near future (Hans-Joachim *et al*., 1996).

In an effort to bring about economic growth and agricultural development, various agricultural sector development strategies were designed in the past few decades. In response to the extensive degradation of land resources in the highlands of Ethiopia, the Ministry of Agriculture has undertaken some efforts to mitigate the problem of soil erosion and maintain the productivity of agriculture by introducing and promoting improved soil and water conservation technologies in some degraded area of the highlands including Anjeni area in the north western part of Ethiopia since 1980s.

However, different evaluations of investments in improved soil and water conservation measures by small farm households indicated that despite the efforts made and high expected benefit from soil and water conservation technologies, farmers appear to be sluggish and unresponsive to use them and the adoption and diffusion of soil and water conservation technologies has remained limited or sub-optimal. In addition, it is indicated that recent development and technology interventions were important but insufficient and the level of impact was very low due to economic, policy and institutional constraints (Gebreselassie, 2006; Kassa, 2005; EEA, 2006).

1.2 Problem Statement

The current situation of land degradation, poverty and food insecurity in Ethiopia is so critical that there is a strong need to enhance agricultural production, productivity and food security through appropriate research, development and technological interventions. Soil erosion by water coupled with soil nutrient depletion in the highlands of Ethiopia might lead to irreversible changes in soil productivity that directly affects the food security situation of small farmers who are extremely dependent on their land and rainfall and cannot support further deterioration of soil productivity. Hence, promoting the use of improved soil and water conservation measures and other policy incentives and technology interventions are crucial to counter land degradation process and to improve the productivity of land and their income.

Due to the continuous dependency on agriculture, land degradation and unfavorable climatic conditions, rural development policies in Ethiopia are challenged by two important issues: a) the need to improve household income to meet the demand for food in the face of growing population and the need to improve or sustain the productivity of land; b) to improve agricultural production and productivity, the agricultural system should depend on conducive policy and technology environments. This highlights the important task of undertaking research to understand and design appropriate policy incentives and technology interventions to understand the potential impacts on sustainable land management, poverty and food security of small farm households.

1.3 Research Questions

The first research question related to the above problem is: ‘‘can small farm households in Anjeni area reverse the process of land degradation and improve their income if they are provided with incentives and utilize the full potential of existing technologies’’? Second, ‘‘why farmers in Anjeni area appear to be so sluggish to use improved soil and water conservation technologies and why the use of soil and water conservation technologies has remained limited or sub-optimal despite the fact that different studies indicated high expected benefit from using soil and water conservation technologies’’?

1.4 Research Objectives

The general objective of this study is to analyze the impact of policy incentives and technology interventions on land degradation and income of small farm households and to assess the factors that influence the use of improved soil and water conservation measures in Anjeni area, North Western Ethiopia. specifically, this study trys to evaluate: a) the Impact of Improved soil and Water conservation technologies; b) the Impact of access to fertilizer credit to finance agricultural inputs; c) the Impact of high yielding crop variety on land quality and income of small farm households in a bioeconomic modeling frame work and d) to identify socioeconomic, institutional and physical factors that influence the use of improved soil and water conservation technologies by small farm households based on an econometric model in order to draw some conclusions and implications for policy that can help promote sustainable land use in the highlands of Ethiopia

1.5 Organization of the Thesis

This thesis contains a total of eight chapters. Chapter one consists of the background, problem statement, research questions and objectives. Chapter two describes the study area, data sources and socioeconomic characteristics of sample households. Chapter three presents an overview of the agriculture sector in Ethiopia and the policy and technology environments. In chapter four, the approaches and methodological issues in bioeconomic modelling are reviewed. The theoretical frameworks and empirical specifications of the bioeconomic model are presented in chapter five. Chapter six presents the baseline model results, the robustness test of the model, sensitivity analysis, policy incentives and technology scenarios. Chapter seven presents an econometric analysis of the factors that influence the use of improved soil and water conservation technologies. Chapter eight presents the summary, conclusions and policy implications and recommends future research areas related to this study.

CHAPTER TWO

STUDY AREA, DATA SOURCES AND CHARACTERISTICS OF SAMPLE HOUSEHOLDS

2.1 The Study Area

2.1.1 Location, Topography and Climate

Anjeni area is located about 365 km North West of Addis Ababa, North-Western Ethiopia, in West Gojjam administrative zone, inside Dembecha administrative district with in an altitude range of 2100 and 2500 meters above sea level. Dembecha administrative district is bordered by Degadamot and Jabitehnan districts to the North, East Gojjam administrative zone to the South and East and Jabitehnan administrative district and Awi administrative zone to the West. Figure 2-1 shows the geographical location of Anjeni area. The absolute location of the center of Anjeni area is approximately $10^0$15'N latitude and $36^0$45'E longitude (kejela, 1995).

Anjeni area receives a uni-modal rainfall. According to the rainfall data recorded by the Soil Conservation Research Project (SCRP) from 1984 to 1994 in Anjeni Soil Conservation Research Station, the mean annual rainfall is estimated to be 1690 mm with a maximum and minimum amount of rainfall of 1372 mm and 1839 mm per year, respectively (SCRP, 2000). The main rainy season, the period in which more than 90% of the total rainfall occurs, extends from May to September (SCRP, 2000). The mean daily temperature of the area is about 16°C with mean daily minimum and maximum temperature of 9°C and 23°C respectively (SCRP, 2000).

The relief of Anjeni area generally reveals a decreasing altitude from North East to South West and the over land water flow drains in this direction to tributaries and rivers towards the Blue Nile basin. The river which drains water flow from most parts of Anjeni area is called Minchet River. Minchet River dissects Anjeni area through the middle. The water flow from the other two sides of Anjeni area also drains through other rivers to the Blue Nile basin. According to Hanggi (1997), the dominant slope category of Anjeni area is estimated to lie between 8% and 30% and described as a rolling to hilly topography resulting in high rate of soil degradation associated with intensive rainfall.

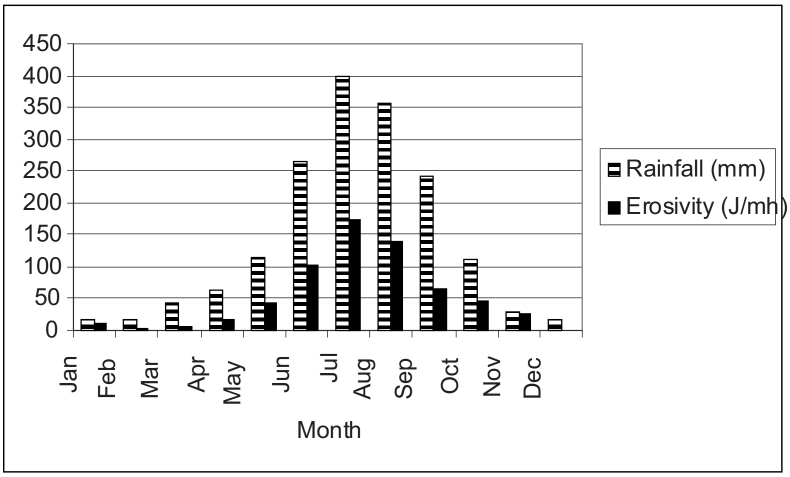
Figure 2.1: Location of the study area

2.1.2 Soil Types, Erosion and Conservation

The soils of Anjeni area are generally acidic and low in organic carbon content, have low to medium total nitrogen and plant available phosphorus contents (SCRP, 2000). The Chemical and physical properties of soils in Anjeni area is given in Appendix-7. According to Hanggi (1997), the soils of Anjeni area have developed on the basalt and volcanic ash of the plateau which covers the Mesozoic limestone and sand stone layers. The major soil types identified with in the soil conservation research project site in Anjeni research station include: Alisols, Nitosols, Cambisols, Regosols and Luvisols (Kejela, 1995, Zeleke, 2000).

Soil erosion in Anjeni area is serious as a result of intensive rainfall, especially in the months of June, July and August. The distribution of rainfall in Anjeni area is given in figure 2.2 below. The rainfall distribution during this period varies between 240.18 mm and 398.20 mm with a peak rainfall in July and with a peak erosivity of 173.5 J/mh (SCRP, 2000). The mean annual soil losses for selected crops in Anjeni area from 1984 -1993 goes as high as 192.6 ton/ha (SCRP, 2000). This indicates that the annual soil loss is generally far higher than the tolerable (acceptable) soil loss of 8-10 ton/ha/year and the estimated rate of soil formation ranges between 2 and 22 ton/ha/year (Hurni, 1988).

Figure 2.2: Distribution of rainfall and erosivity in Anjeni (1984-1993)



Source: SCRP (2000)

Despite past efforts made by the ministry of agriculture and soil conservation research project, soil erosion still remains to be a serious problem. Farmers in Anjeni area use both traditional and improved soil and water conservation structures. They form diagonal ditches across their farm plots to remove water that results in critical runoff in smoothly tilled crop lands. Some farmers use improved soil and water conservation measures such as soil bund and stone bund which were first initiated by soil conservation research project in the 1980s and promoted by the ministry of agriculture and rural development. Currently, more than 50% of the farm plots of sample farm households don't have improved soil and water conservation structures. The most widely used improved soil and water conservation measures by farmers are improved soil bund and improved stone bund. Usually, farmers use a mixture of soil and stone bunds as there are no stones available across their farm plots.

2.2 Data Sources

The analysis of this study is based on a combination of both primary and secondary data that are collected from Anjeni area, north-western Ethiopia, from the Ministry of Agriculture and Rural Development and other national and international organizations.

2.2.1 Primary Data and Survey Design

Anjeni area is a typical representative of the rain-fed, cereal based, smallholder ox-plough mixed farming system which comprises significant proportion of the highlands of North-Western Ethiopia. In addition, the choice of the study area was motivated by the presence of biophysical data on soil erosion and the effect of soil conservation measures to curb soil erosion conducted by Soil Conservation Research Project (SCRP) since mid 1980s. Anjeni area has been chosen by Soil Conservation Research Project (SCRP) as an experimental site in 1984 and soil conservation experiments were undertaken until 1993.

The study area is stratified in to upper and lower Anjeni areas in order to capture the heterogeneity of small farm households in terms of resource endowment, farm plot characteristics and distance from the main road and the district town, which is the major market for both areas. After stratifying the area in to upper and lower Anjeni, the optimum sample size to be selected from the total population was determined.

Usually, the sample size question is answered by dividing an exogenously fixed survey budget by the unit cost of interview or one might just pick a random number. However, this approach can't balance the gains to additional sampling effort against the extra interviewing costs. Generally, the more we know about the population, the better we can plan our sampling design. This requires collecting information on the population needed for planning a survey design, either from literature or from a pilot study, given the available resources at hand (money, time, personnel and other resources needed to conduct a survey). According to Levy and Lemeshow (1999), to estimate the mean value of a given variable of interest for a population size (N) with, for example, a 95% confidence level, the sample estimate $\bar{x}$ should not differ in absolute value from the true unknown population parameter μ by more than $\varphi.\mu$. Where φ is the maximum relative difference given in percent of true value, i. e.;

(2.1) $$p\left(\left|\frac{\bar{x}-\mu}{\mu}\right| \leq \varphi\right) \geq 0.95$$

In order to determine the sample size that can give reliable[1] results, prior knowledge of the population size, sample estimate (mean) of a parameter and its standard deviation in the whole population, estimate of the maximum relative difference and the confidence level are needed. The exact sample size (n) required to estimate the mean value of a population using random sampling is given by equation (2.2) (Levy and Lemeshow, 1999).

(2.2) $$n \geq \frac{z^2 N \eta_x^2}{z^2 \eta_x^2 + (N-1)\varphi^2}; \qquad \eta_x^2 = \frac{\left[(N-1)/N\right] s_x^2}{\bar{x}^2}$$

Where Z denotes the reliability coefficient for a given confidence level (e.g., $Z = 1.96$ for a 95% confidence level), N is the population size, $\bar{x}$ is the sample mean and s^2 is the sample variance. If more than one variable are considered, we should calculate the optimal sample sizes for each variable and the final sample size chosen might be, then, the largest of the calculated sample sizes for each of the variables (Levy and Lemeshow, 1999).

[1] Reliability indicates how reproduceable an estimator is over repeated sampling. The smaller the standard error the greater is the reliability

Based on this, the estimates of two variables of interest were taken from other studies carried out in Anjeni area and the optimal sample sizes were determined based on the average estimates and standard deviations of these variables. The variables considered are area of cultivated land in hectare and *Teff* output per hectare. After calculating the sample size based on the two variables the optimal sample size was decided to be 200 households. Then, a proportionate random sampling procedure was followed to select a total of 200 sample farm households.

After selecting the sample households, training data collectors and pre-testing the questionnaire, a general farm household survey was conducted using semi-structured questionnaires. However, due to incompleteness and inconsistency of information four questionnaires are dropped out during data cleaning stage leaving the total number of sample households to be 196.

In the second round, an in depth survey was also conducted on 10 representative farm households. Group discussions were also undertaken on major problems and practices related to agriculture production and land management decisions. The data collected in the general household survey include demographic and socioeconomic characteristics such as source of income and expenditure patterns, access to credit and market and other related information. Plot level data include information on production activities and labour supply decisions, input use and intensity of soil and water conservation measures. It also involved the collection of biophysical information related to soil type and farm plot characteristics.

Table 2.1: Sample information

Study area	Population size	Maximum relative difference (percent)	Confidence level	Population proportion	Sample size
Upper Anjeni	624	10	0.95	0.58	115
Lower Anjeni	451	10	0.95	0.42	85
Both areas	1075	10	0.95	1.00	200

2.2.2 Sources of Secondary Data

The biophysical data from Anjeni area collected by Soil Conservation Research Project (SCRP) since March 1984 is used in this study. The data from the Soil Conservation Research Project (SCRP) doesn't include current information but it is the only available information for bioeconomic modelling of the decision of farm-households on land management. Though the data is incomplete, some important information related to soil nutrient content, soil erosion, and soil conservation measures and their effects on soil erosion and nutrient depletion are found to be important input in this study. This data set also contains information on soil erosion and run-off experiments in Anjeni area. In addition, different types of data are used from different secondary sources including national and international organizations and different departments and ministries in Ethiopia.

2.3 Classification and Characteristics of Sample Households

2.3.1 Classification of Sample Households

Though small farm households in the high lands of Ethiopia possess many similar socioeconomic and cultural characteristics, they are also heterogeneous, i.e., they have different needs, own different resources such as land, labour and livestock and face different constraints. These differences in resource endowment and other constraints influence their capacity to respond to different opportunities and challenges brought about by external factors such as policy incentives and technology interventions.

Thus, analysis of effective development policy incentives and technological interventions require understanding of these differences, proper identification of the variations and classification of farm households in to, relatively, homogenous groups of households or clusters so that analysis can be made on farmers that have relatively similar circumstances to policy incentives and technology interventions. Grouping farm households for policy analysis requires setting criteria for grouping and identifying indicator variables which measure the stated criteria (Yilma, 2005). In case when only one variable is enough to fully classify groups of households, the identification of these distinct groups could be done based on quartiles of this important variable (Yilma, 2005). However, when multiple variables are considered, factor analysis and principal component analysis are used to develop common criteria for clustering based on selected variables. In this study, factor analysis with a principal component extraction method is used to determine common dimensions based on selected variables to classify farm households in to relatively homogenous groups.

2.3.1.1 Factor Analysis

Factor analysis is a multivariate statistical method used to describe variability among observed variables in terms of fewer unobserved variables called factors. It addresses the problem of analyzing the structure (correlation) of variables by defining a set of common underlying dimensions (factors). The principal components method of extraction begins by finding a linear combination of variables (a component) that accounts for as much variation in the original variables as possible. It then finds another component that accounts for as much of the remaining variation as possible and is uncorrelated with the previous component, continuing in this way until there are as many components as the original variables. Usually, a few components will account for most of the variation and these components can be used to replace the original variables.

The description of variables selected for household group classification in factor analysis is given in table 2.2.The selection of variables is based on the assumption that differences in resource endowment and constraints and farmers' knowledge and understanding towards external environment could influence their capacity to respond to different opportunities and challenges brought about by policy incentives and technological interventions.

Table 2.3 shows the Kaiser-Meyer-Olkin (KMO) test statistics for sampling adequacy and Bartlett's test of sphercity (homogeneity of variance). The values and the level of significance indicate that a factor analysis is useful and relevant. Hence, all variables are included in the factor analysis. Based on factor analysis with principal component extraction method, three components with Eigen value greater than one were extracted from the variables included. The extracted components explained more than 60% of the variability in the original eight variables. Component one, being the strongest, explained more than 23 % of the variability in the original variables.

Table 2.2: Description of classification variables used in factor analysis

Variables	Mean	Std. Deviation
Land size (ha)	1.07	0.41
Family labour (md)	2.80	1.11
Livestock units (TLU)	4.49	2.26
Value of household equipment (ETB)	388.70	1455.90
Age of household head (years)	45.20	13.70
Education of household head (1 literate; 0 otherwise	0.70	0.46
Location (1 upper Anjeni; 0 otherwise)	1.41	0.49
Distance to urban Center (km)	18.11	1.64
Total Number of sample households	196	

Source: Own survey (2007)

Table 2.3: Test for sampling adequacy and Bartlett's test of sphercity

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.60
Bartlett's Test of Sphericity	Approx. Chi-Square	204.01
	df	28
	sig.	0.000

The rotated component matrix, in table 2.4, shows the factor loadings (correlations of components and variables) of the classification variables. It helps to determine what each component represents. The variables land size, family labour, livestock units and age have the largest factor loadings on the first factor, implying that the first component is most highly correlated with land size, family labour and age of the household head and moderately correlated with livestock units.

The second component is most highly correlated with location and distance to urban center as these variables have the highest factor loadings on the second component. The third component is most highly correlated with education and moderately correlated with the value of household equipment.

Based on the rotated component Matrix, the group of variables are defined by the three factors in order to give focus for further analysis. Since, variables land size, family labour and livestock units indicate the resource constraint of farm households, component one is referred to as ‘resource endowment’. The second component, associated with variables location and distance to urban center, is interpreted as ‘location’ and the third component is interpreted as ‘literacy’ as it is most highly correlated with education.

Table 2.4: Rotated component matrix

Variables	Component		
	1	2	3
Land size (ha)	0.765	0.069	0.003
Family labour (md)	0.715	0.017	0.235
Livestock units (TLU)	0.529	-0.179	0.506
Value of household equipment (ETB)	0.059	-0.089	0.408
Age of household head (years)	0.717	-0.126	-0.445
Education of household head:1 literate; 0 otherwise	-0.060	0.064	0.842
Location: 1 upper Anjeni; 0 otherwise	-0.064	0.870	0.000
Distance to urban Center (km)	0.045	0.830	-0.108
Extraction Method: Principal Component Analysis Rotation Method: Varimax with Kaiser Normalization			

2.3.1.2 Household Groups (Clusters)

Clustering is the assignment of a set of observations into subsets called clusters so that observations in the same cluster are, relatively, homogenous in some sense. The factor scores from the previous analysis are used as clustering criteria. A Hierarchical clustering technique was used to classify sample households in to two major groups (clusters) with cluster members of 106 households for group one and 90 households for group two. Independent samples test (test for equality of variances) and t-test for equality of means for the household groups were conducted. Description of household classification variables for the two groups and Independent samples test for household groups are given in table 2.5.

Table 2.5 : Description of variables and independent samples test

Variables	Groups (clusters)	Mean	Std. Dev.	Independent samples test for household groups	
				Levene's test for equality of Variances (F- values)	t-test for equality of means
Land size (ha)	1	0.914	0.381	0.249	-6.206**
	2	1.252	0.376		
Family labour (md)	1	2.314	0.865	8.823**	-7.807**
	2	3.400	1.083		
Livestock units (TLU)	1	3.276	1.699	1.619	-10.408**
	2	5.986	1.943		
Value of equipment (ETB)	1	183.70	100.6	10.168**	-2.206*
	2	640.3	2149.9		
Age of household head (years)	1	43.1	14.6	6.200	-2.358*
	2	47.7	12.2		
Education of household Head:1 literate; 0 otherwise	1	0.54	0.50	206.680**	-6.177**
	2	0.91	0.23		
Location:1 upper Anjeni; 0 otherwise	1	1.56	0.498	36.740**	5.052**
	2	1.23	0.421		
Distance to urban Center (km)	1	18.67	1.37	11.978**	5.741**
	2	17.42	1.68		
Percent of households	1	106 (54%)			
	2	90 (46%)			

Note: ** and *, respectively, indicate significance at less than 0.01 and 0.05 probability levels

2.3.2 Characteristics of Sample Households

Farm households in Anjeni area are heterogeneous in some respects and homogenous in some others. Classification of sample farm households in to two different groups is carried out in section 2.3.1. The two groups of households differ in the classification variables. As compared to household group one, household group two comprises of households endowed, relatively, with better resources such as land and labour.

Livelihood in the study area depends mainly on crop and livestock production activities and the size and quality of land and family labour are the most important resources employed in agricultural production. This section describes the demographic and education characteristics of sample households, labour, land and farm plot characteristics and highlights the nature of crop production activities.

2.3.2.1 Demographic and Education Characteristics

Population size and characteristics are directly related to the supply and demand conditions for basic human necessities such as food, shelter and other facilities which in turn influence the use of improved technologies and the natural resource basis. The age and educational characteristics of sample farm households is given on table 2.6.

Table 2.6: Age and educational characteristics of sample households

Characteristics	Number	Percent
Age group (household heads)		
Below 30	37	18.9
30-45	62	31.6
46-64	76	38.8
Above 64	21	10.7
Total	196	100.0
Family size of households		
Less than 3	11	5.6
3 to 5	81	41.3
6 and above	104	53.1
Total	196	100.0
Education of household heads		
Illiterate	58	29.6
Adult/religious education	81	41.3
Primary education	49	25.0
Secondary education	8	4.1
Total	196	100

Source: Own survey (2007)

The average age of the sample household heads is 45 years while the average family size is 5.6. Family size of sample households ranges from 1 to 10 persons. While 29.6% of sample household heads are illiterate, only 25% have primary education and 8% have secondary education. The rest, 41.4%, do have informal (religious or adult) education. This low level of education may affect farmers' ability to obtain and use information relevant to the use and management of improved agricultural technologies, including improved soil and water conservation measures.

2.3.2.2 Labour, Land and Plot Characteristics

Farmers engage in different economic activities such as ploughing, weeding, harvesting and transporting of crops. The amount of labour available for such activities is determined by the size and composition of the working part of household members. Hiring external labour is not common and households mostly depend on family labour. The available labour force per household is calculated based on the age and sex composition of household members and a conversion factor was used to estimate labour equivalent in man days (Storck *et al*., 1991). The average available labour for household group-I and household group-II were estimated to be 2.3 and 3.4 man days respectively. Farmers reported that the use of hired labour is almost nonexistent due to small land area that can only be cultivated using family labour and due to financial constraints of farmers to pay wage for external labour.

Land in the study area is scarce due to population pressure. The average area of cultivated land is 0.98 ha (st.dev. =0.38). The size of cultivated land varies between 0 (land less) and 2.12 ha. As a result of small size of land holding in the area and land fragmentation, fallow lands are not common and shortage of grazing land for livestock production is one of the major problems facing livestock production.

The survey result also showed that land holding is not only small but also fragmented and sloppy. The average number of farm plots across the whole sample farm households was found to be 4.14 (st.dev. = 1.125). The number of farm plots varies from 0 (for land less) to 6. In addition, the slope of the farm plots affect soil erosion and the decision to use soil conservation measures to curb soil erosion. More than 62 % of farm plots have steep (5-15%) or very steep (>15%) slopes implying a strong need to use improved physical soil and water conservation measures.

2.3.2.4 Crop and Livestock Production Activities

Land fragmentation has led farmers to waste considerable amount of time and energy while travelling from one plot to another and the loss of agricultural land due to large number of borders between plots owned by different farmers in different locations. Some farmers, however, argue that having different plots of land at different location reduce natural risks such as heavy rain damage or runoff and animal pests.

Agriculture in Anjeni area is rain-fed, cereal-based, smallholder, ox-plough farming system. Crop production is the dominant economic activity in the area. The small-scale subsistence farming system employs very simple implements and traditional methods of crop production. Mixed farming, involving complementary interactions between crop and livestock production, using animal for traction and their manure as fertilizer for crop production and feeding crop residues to livestock, are the dominant production system in the area. The major crops grown in Anjeni area include: *Teff*, Barley, Wheat and Horse Bean. Fallow lands are not common, sloppy and marginal lands are used for cultivation.

Livestock production is also an important sub sector undertaken in line with crop production in Anjeni area. Animals are indigenous (local breeds) and used as sources of milk, meat, cash, draught power, fuel and means of transport. Farmers reported that shortage of animal feed is the major problem of livestock production in the district. The main sources of feed for animals are crop straw and communal grazing lands. Especially, the availability of oxen is the most determinant factor for crop production where oxen power is a major production input. Out of the total respondents, 8.7% do not have ox, 27% have one ox, and the remaining 64.3% have two or more oxen.

CHAPTER THREE

AGRICULTURE, LAND DEGRADATION AND DEVELOPMENT POLICIES

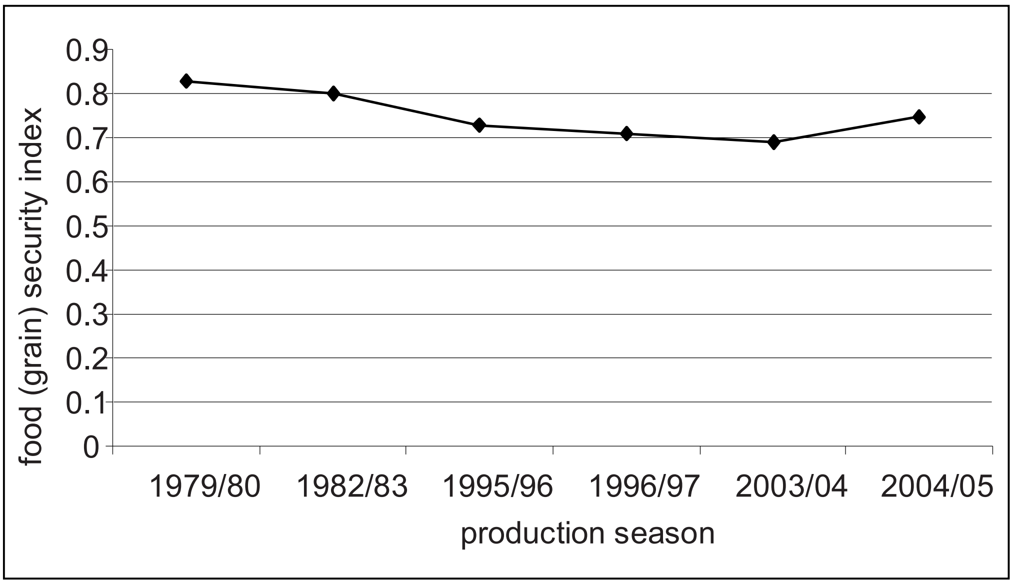
3.1 Performance of the Agriculture Sector in Ethiopia

Agriculture, the dominant economic sector in Ethiopia, is characterized by low productivity and subsistence nature of crop and animal production systems. Agricultural production relies heavily on traditional technologies unchanged for many years and the use of external yield increasing inputs is rudimentary (Bogale, 2002). Moreover, agricultural production in the country is heavily dependent on rainfall. According to the Central Agricultural Census Commission (CACC, 2004), 96.8 percent of the total land area is held by small holder farmers and the irrigated area made only 1.8 percent of the actually cropped land.

The size of land holding has gradually diminished over the years due to high rate of population growth and many farmers operate on fragmented plots of land. In 2000 cropping season, 87.4 percent of rural households operated on less than 2 hectares; whereas 64.5 percent of them cultivated on farms less than one hectare; while, 40.6 percent operated on land size of 0.5 hectare and less (CSA, 2003). Small farms are fragmented, on average, into three parcels per holder or 0.3 ha per parcel, leaving no room for economics of scale and commercialization of agriculture (Mengistu, 2005). The negative impact of small farm size is also reflected by low land productivity and this problem is further complicated by high population pressure and lack of employment in the non-farm sectors.

The per capita food production has been declining over the past two and half decades. The increase in production, mainly due to area expansion, is by far lower than the rate of population growth and the level of national food security deteriorates. As shown on figure 3.1 below, the level of per capita food (grain) production in Ethiopia has declined between 1979/80 and 2004/05 production seasons. This decline has been mainly attributed to the high rate of population growth (Gebreselassie, 2006). During the past two and half decades, population has almost doubled (grew by 97%), while agricultural production, mainly through area expansion, has increased only by 59%, implying a negative growth in per capita agricultural production (EEA, 2006).

Figure 3.1: Food (grain) security index



NB. The index is based on 210kg/person = 1.0; Source: adapted from EEA (2006)

Land in Ethiopia is a public property that has been administered by the government for more than three decades. Farmers have open-ended (vague) use rights to agricultural land and restricted right to transfer or lease their use right. Some argue that one of the policy instruments to halt the undesirable relationship between small farmers and nature in Ethiopia is the lack of an appropriate land tenure system.

Tenure security is an important factor that affects technology choice and utilization by small farm households. Insecure land tenure prevents farmers from realizing economic and non-economic benefits that are normally associated with secure property rights in land, such as, greater investment incentives, transferability of land, improved access to long-term credit, more sustainable management of resources and independence from discretionary interference by bureaucrats. These imperfections in the land policy and administration assumed to undermine the value of land and consequently discourage intensification and long-term investments on land improvements (Deininger *et al*., 2003).

3.2 Land Degradation and Productivity of Agriculture

Land degradation has contributed to declining productivity of Agriculture and brought poverty and food insecurity in the country. A report by Tefera *et al*. (2000) indicated that the rate of soil formation in Ethiopia varies between 2 and 22 tons per hectare per year, while soil loss rate ranges from 51 to 200 tons per hectare per year in most highlands. This result shows that the rate of soil erosion is almost 10 to 25 times the rate of soil formation. Stoorvogel and Smaling (1990) reported that Ethiopia has among the highest estimated rates of soil nutrient depletion in Sub-Saharan Africa which reduces productivity and increase farmers' vulnerability to drought. For example, estimates of soil nutrient loss in Ethiopia show a net removal of 41 kg of nitrogen/ha of agricultural land between 1982 and 1984 and losses were projected to reach 47 kg/ha by the year 2000 (Stoorvogel and Smaling, 1990).

Loss of soil fertility is also manifested through limited recycling of manure and crop residue in the soil, low use of chemical fertilizers, declining fallow periods, soil and organic matter burning, and soil erosion. Although the farming system in the highlands of Ethiopia is predominantly mixed crop-livestock, nutrient flows between the two are predominantly one sided, with feeding of crop residues to livestock but little or no dung being returned to the soil. This phenomenon is common in most highlands of Ethiopia where the nutrient balance is highly negative (de Wit *et al*. 1996, cited in FOA, 2003).

Deforestation is prevalent and contributes to land degradation and biomass is the primary source of energy. For example, biomass, cow dung and crop residues account for 99% of the total fuel needed for domestic cooking and heating in the household sector in Amhara region (BoA, 1997). Different studies examined the rate of land degradation in Ethiopia. However few of them have looked at the impact of land degradation on productivity. Kappel (1996) has reviewed the net soil loss from different studies to be in the range between 20 ton/ha/year and 100 t/ha/year, with an annual productivity loss on crop land to be between 0.12% and 2% of the total production for the country as shown in the table 3.1 below. Using 1994 prices, an annual yield loss of 1% of 1992 production was valued at about US $7.5 million (Kappel 1996).

Table 3.1: Soil erosion and productivity loss in Ethiopia.

Erosion and productivity loss	Wright and Adamseged (1986)	Hurni (1988)	Sutcliffe (1993)	Bojo & Cassells (1995)
Soil loss (t/ha/year)				
Gross	130	-	-	40
Net	100	42	45	20
Productivity loss (% output /year)				
Potential	-	-	0.7	0.4
Effective	1.8	2.0	0.21	0.12

Source: Kappel (1996)

3.3 Agricultural Development Policies and Strategies: Recent Experiences and Constraints

Agricultural development policies and strategies play a significant role in influencing farmers' decisions with respect to production, consumption and land management. Significant productivity growth can be achieved by improving farmers' access to technologies and improved practices which can narrow the gap between farmers' yield and the potential yield. To this end, policy incentives and technologies need to be evaluated and carefully planned in line with the felt needs of smallholder farmers and fit the agro-ecological and socio-economic circumstances in a manner that can bring the highest benefit.

Various agricultural sector development strategies have been undertaken in the past four decades by different governments in Ethiopia in an effort to bring about economic growth and agricultural development. The main agricultural development strategies were: the Comprehensive Package Programmes (CPPs) of the mid 1960s and early 1970s, the Minimum Package Programmes (MPPs) of the late 1970s and early 1980s, the Peasant Agricultural Development Programmes (PADEPs) of the late 1980s and early 1990s and the Agricultural Development Led Industrialization (ADLI) strategy developed by the current government in the 1990s (Desta *et al*., 2000). The main objectives of these agricultural development programs were to increase agricultural productivity, reduce poverty and increase the level of food security in the country.

The Agricultural Development Led Industrialization (ADLI) strategy, developed in 1993, sets out agriculture as a primary stimulus to generate increased output, employment and income for the people and as a spring board for the development of other sectors of the economy (Gebreselassie, 2006). The major objectives of the five-year development plan include: development of the economic and social sectors in order to produce sufficient food and to improve the general employment opportunities for the fast growing population, setting up a better economic management system to withstand droughts and other natural disasters, laying the foundation for sustainable development in the country (Gebreselassie, 2006).

According to Gebreselassie (2006), among others, the strategies designed to achieve these major objectives of the development plan include: promotion of agricultural development led industrialization along with conservation of natural resources; intensification of agricultural production through higher use of inputs; promotion of traditional and small-scale irrigation; use of improved seeds, fertilizer, credit and extension services; enhanced conservation practices of natural resources and reforestation efforts and creation of income-generating activities.

Under the wider strategy of Agricultural Development Led Industrialization (ADLI), the government formulated a smallholder intensification extension programme Known as the Participatory Agricultural Demonstration Training and Extension System (PADETES) in 1994/95 to achieve pro-poor sustainable development in rural areas through increasing farm productivity, reducing poverty and increasing the level of food security (Gebreselassie, 2006). It was a technology-based, supply-driven intensification which consisted of enhanced supply and promotion of improved seeds, fertilizers, on-farm demonstrations of improved farm practices and technologies, improved credit supply for the purchase of inputs and close follow up of farmers’ extension plots (Kassa, 2005).

Efforts have been exerted to disseminate packages of agricultural technologies and practices. As a result, fertilizer use grew by 39% from 190 thousand metric ton in 1994 to 264 thousand metric ton in 2003 and the use of improved seeds also increased from 1,184 metric ton in 1995 to 17,778 metric ton in 1999 (MoRAD, 2003). Despite huge effort to disseminate technologies, mainly fertilizer and improved seeds to smallholders, the intensification program did not lead farmers to improve the level of national food security and reduce rural poverty (Gebreselassie, 2006).

Discussions on the 1990s government effort to boost agricultural production through intensification of smallholder agriculture identified many problems that contributed to the loss of momentum or sustainability of initial promising achievements. Evaluation of these program shows that the technological interventions were important but insufficient and the level of impact was very low due to economic, policy and institutional constraints (EEA, 2006). For example, only half of the farmers participating in the program used improved seeds. Among them, 20% of early adopters discontinued their use of improved seeds immediately after their participation come to an end. Only 8% of sampled farmers reported their frequent use of improved seeds (EEA, 2006).

It is also shown that only 22% of the households used complete package of crop production, i.e., improved seeds, fertilizer and improved practices with the recommended amounts. Most of the households (78%), who were participating in extension package programme, used an incomplete package of crop production, lacking one or more of the major components (EEA, 2006).

According to Gebreselassie (2006), the programme failed to give due attention to the complex factors and diverse situations influencing agricultural and rural development. The programme could be considered as a ‘one-size-fits-all’ strategy that failed to recognize variation in terms of agricultural potential (land, soil fertility, water resources) and the limitation of technology oriented intervention to solve the complex and many faceted rural problems of low agricultural productivity, poverty and resource degradation. This requires addressing further the question why has smallholder sector not intensified despite numerous efforts to encourage technology-led growth over the past decades.

Despite the many constraints facing agricultural development in the highlands of Ethiopia, there appear to be many opportunities to achieve more productive and sustainable agriculture development. Nevertheless, there is a continuing need in the long term to bring about a balanced development of both the farm and non-farm sectors to achieve a more sustainable use of the land, economic growth and elimination of poverty (Desta *et al*., 2000).

The Ethiopian highlands consist of a large geographic area with a high variation in agricultural potential and constraints. The government's pro-poor intensification programme in the 1990s was a general national extension programme that couldn't create opportunities for smallholders working in different agro-ecology and heterogeneous production environments and farming systems to exploit the opportunities specific to each area. Since, factors that influence sustainable land management and rural development are complex, 'one-size-fits-all' strategy don't work for all areas. This requires developing farther alternative development pathways or opportunities for rural development that may be economically feasible based on agriculture potential, market access and population density in different types of circumstances and the policy, institutional and technological strategies needed to exploit these opportunities (Gebreselassie, 2006; Desta *et al*., 2000).

CHAPTER FOUR

REVIEW OF APPROACHES AND METHODOLOGICAL ISSUES

4.1 Introduction

In dealing with land management and agricultural production, two major processes take place. The first one is the biophysical process related to soil erosion, soil nutrient depletion and crop growth. The second one deal with socioeconomic aspects related to household behaviour, technology and policy incentives, market structure and institutional arrangements such as access to credit and input supplies. This implies that, in addition to economics, contribution from biophysical sciences is required to analyze the possible effects of a given policy incentives and/or technology on land management and crop production.

However, analyzing such type of problem in an integrated approach is difficult as the results from the analysis of one discipline may not fit to the other one unambiguously due to the difficulty in communication between different disciplinary languages (Kruseman, 2000). Recently, major advances have been made in combining biophysical and socio-economic aspects of these problems in a more comprehensive and integrated modelling approach. Integrated quantitative modelling approaches, called bioeconomic models, have been developed and applied to ease communications between different disciplines and facilitate the analysis of land degradation and other environmental problems in developing countries (Brown, 2000).

The rest of this chapter is organized as follows. In section 4.2, a brief review of bioeconomic models is presented; section 4.3 discusses about bioeconomic modelling approaches; section 4.4 discusses the different levels of aggregation in bioeconomic models and section 4.5 describes production functions in the context of land management and finally, the state of research on land degradation in Ethiopia is described in section 4.6.

4.2 Review of Bioeconomic Models

Though, the concept of bioeconomic models represents a wide range of interdisciplinary modelling and is applied in areas ranging from industrial pollution in developed countries to agro-ecological systems (natural resource management) in developing countries, the main focus in this study is based on the current approaches to modelling of natural resources management, particularly, sustainable land management in developing countries.

Brown (2000) has reviewed and classified 21 bioeconomic models representing different modelling approaches ranging from simple empirical models to complex integrated models. The main criterion he used for classification is the extent of integration between socioeconomic and biophysical components of the models and developed a continuum of bioeconomic models whereby, at one extreme end point of the continuum are those that are primarily biological process models to which an economic analysis component has been added, at the other extreme end point are the economic optimization models with some biophysical features and at the center of the continuum are the fully integrated bioeconomic models.

While the more sophisticated biological process models attempt to model the underlying processes or mechanisms at a more basic level, some other forms are based on empirical measures of biological processes. According to Brown (2000), biological process models mimic the actual biological process involved at various scales and over various periods of time and most of them incorporate some cost and benefit component in their analysis, hence they fall into the extreme point of the continuum in his classification.

Brown (2000) has also pointed out that economic optimization models with some biophysical features uses a fixed set of parameters for a finite set of activities derived from empirical observation but do not model the agro-ecological process involved in such a way as to simulate the actual biological processes. More sophisticated economic optimization models with biophysical features account for the possibility of multiple objectives of a decision making unit and there by the priorities and constraints of households or the aggregate objective at a community or watershed level accounting for a dynamic interdependence through the use of a multi-period modelling approach. On the other hand, other optimization models take a relatively simple approach to incorporate biophysical processes in to the modelling framework. For example, they include a component which measures the biological or ecological sustainability of the system being modelled.

Brown (2000) has put the fully integrated bioeconomic models at the midpoint of the continuum and explained that a truly integrated bioeconomic model must include the socioeconomic feature of the economic optimization models on the one hand and the biological process simulation features on the other hand. However, as one moves towards the center of the continuum, greater efforts and advanced techniques are required to model the socioeconomic and biophysical aspects simultaneously. Brown (2000) pointed out that the most challenging task in fully integrated bioeconomic models is to bring both ends of socioeconomic and biophysical modelling continuum together without losing the essential elements or compromising the strength of either.

To be fully integrated, bioeconomic models have to satisfy a number of requirements Brown (2000): one of the most important elements of these models is to be recursively dynamic. Since biophysical processes are dynamic in their responses to environmental changes and the linkage from one period to the other involves a sequential set of decisions and outcomes that establish initial conditions for the next set of decisions. Second they need to fully incorporate issues of temporal and spatial scale. Third, since the unit of analysis tends to be the household, there is also a need to incorporate issues of risk and uncertainty management, because the consequence of living at the margin of possible livelihoods means that downside production risks have immediate and possibly irreversible consequences for consumption.

Kruseman (2000) has distinguished bioeconomic models based on two main criteria: temporal and spatial scale or level of aggregation. He then combined the two criteria in a matrix of possible approaches in bioeconomic modelling. Based on time scale, he made a distinction between past, present, near future and far future. The other distinguishing criterion he used is the special scale or the level of aggregation at which the study takes place. According to this criterion, the aggregation level can be made at plot level, enterprise level, farm household level, village/watershed level and regional or higher levels.

4.3 Bioeconomic Modeling Approaches

Optimization models allow combining biophysical and socioeconomic data at different scales with expert information and stylized facts and need to be adapted to the scientific reality of farm household research in developing countries (Börner, 2005). Generally, both normative modelling approaches, based on the principle of optimization, and positive modelling approach, based on econometric techniques, have been used in bioeconomic modelling. However, lack of compatible data set in developing countries makes constructing econometric household models with integrated biophysical component practically impossible (Kruseman, 2000).

Bioeconomic modelling techniques at different levels can assume different methodologies: linear programming, dynamic programming, optimal control models, farm household models or computable general equilibrium (CGE) models. Linear programming optimization procedure, both in static and dynamic frameworks, can be used as a method for the appraisal of farm households' response to policy incentives. If relevant data is available, dynamic optimization models can be used to consider the inter-temporal interactions between soil erosion, conservation, farming activities and soil quality attributes, hence allow incorporating feedback effects of economic factors on land management decision (Tizale, 2007).

Bio-economic models at the farm level can also make use of procedures developed for farm household modelling that specify the underlying behavioural relationships regarding farm household resource allocation and consumption priorities (Singh *et al.*, 1986; De Janvry *et al.*, 1991). These models explicitly account for resource endowments, input and production factor allocation decision, and output choice and consumption preferences under different conditions of market development. Biophysical information can be linked to the production side of a farm household model by making use of mathematical programming techniques.

Integrated bio-economic farm household models that rely on technical production options derived from production ecology and land evaluation have also been developed (Kruseman *et al*., 1995; Kruseman and Bade, 1998). In these models econometric techniques are applied to specify farm household behaviour regarding consumption and risk. These equations are combined with information from the biophysical sciences into simulation models that are calibrated using data derived from farming systems research. These models enable the assessment of supply response of farm households to different policy incentives taking into account different criteria such as income and land quality.

Village level CGE models and dynamic simulation models have been used to analyze villages and watersheds. At the aggregate level, the use of CGE models is appropriate for analyzing the interactions between different sectors and markets in the complex setting of feedback mechanisms. The main problem with CGE models is that substantial amount of data is required. As a result of this, strong simplifying assumptions are usually made. The problem with this type of model is that, in defining production in terms of sectors without making technology choice endogenous, soil degradation becomes a deterministic process.

At sector level, an integrated multi-level analysis, where stylized farm household models are linked to markets with partial equilibrium analysis and different regions are linked with spatial equilibrium models using mathematical programming techniques to simulate the effects of policy change in a recursive dynamic approach with delayed feedback mechanisms (Gérard *et al*., 1998).

Most available approaches developed call for explicit treatment of biophysical processes and socioeconomic activities. At different levels of analysis these processes interact in different ways. At the field level biophysical processes dominate, while at the farm level there is a strong interaction between the biophysical and decision making processes. At higher levels of aggregation, the interaction between the two realms becomes more difficult to model, since the effects of aggregate behaviour and policy change on soil quality are indirectly interlinked and reciprocal (Kruseman, 2000).

4.4 Aggregation Levels in Bioeconomic Models

Generally, aggregation in bioeconomic models can be made at different levels: plot level, enterprise level, household level, village level, watershed level and regional or higher levels. However, there are different principles that may guide the choice of aggregation level in bioeconomic modelling. From the point of view of economics, the relevance to modelling is the point where decision is made. Generally, the farm household is the focal point of microeconomic analysis. However, other conditions or principles, such as heterogeneity of households and integration between households also affect the choice of aggregation levels. For example, a combination of household and village level analysis might be necessary when there is high degree of differentiation between households and when the integration between households is significant with a non-negligible transaction costs (Kruseman, 2000).

Moreover, analyzing the effect of certain policies on the agriculture sector or a region always relies, implicitly or explicitly, on decision making at the farm household level. The degree of heterogeneity and the degree of integration of households in exchange mechanisms for inputs, commodities and production factors determines the kind of modelling approach that is appropriate. For example, with high transaction costs and low farm differentiation, the assumption of non-separability of household decisions when market access is not possible without trade is realistic. With low transaction costs, irrespective of the degree of differentiation, separable farm household models can be used (Singh *et al* 1986). On the other hand, with high level of differentiation, local market clearance has to be taken in to account unless transaction costs are very low. Depending on the level of transaction costs, CGE models with separable or non separable household models can be used. If the CGE model can't be fully specified, partial equilibrium models for tradable commodities can be used (Bade *et al*., 1997).

On the other hand, Kruseman (2000) discussed some of the most important issues at each level of aggregation and the principles that guide the levels of aggregation. At the lowest level of aggregation many of the biophysical processes are studied and are crucial elements in the model but behavioural aspects are exogenous. In models that are aggregated at watershed level, decisions taken uphill affect the production possibilities downhill through the run-off and erosion and/or sedimentation. At village level, factor markets with in a village for land, labour and capital are balanced through exchange relations and/or tenure arrangements. At higher level of aggregation macro-economic relationships and physio-geographic units predominate and the influence of individual household is of little importance.

4.5 Production Function in the Context of Land Management

The interaction between biophysical process, resource use, technology choice and allocation of other factors of production is usually captured by the production function. In dealing with land degradation, incorporation of soil quality or fertility as a factor of production forms the basis of interface between biophysical and socioeconomic aspects (Kruseman, 2000). The important factors to be considered when linking these aspects are the nutrient-soil-crop interactions and the need to specify a functional relationship between factors which incorporate behavioural aspects.

There are two ways for integrating a production function in to a bioeconomic modelling aimed at analyzing land degradation. The first approach is to calculate input-output coefficients using agro ecological models. For each unique and feasible combination of production conditions (management options), inputs and outputs are determined. The processes and relationships underlying the inputs and outputs of land use activities are based on basic information on soils, climate, and crops and results of documented models and/or quantified expert knowledge (Kruseman, 2000). Although, the use of input-output coefficients (Leontief production technologies) is liable to subjectivity, it is still useful due to its flexibility in allowing adjustments of data and assumptions whenever new information and insights are available (Tchale, 2005; Krusman,2000).

The second approach incorporates environmental information directly into the production function analysis using econometric techniques (Mausolff and Farber, 1995; Pattanayak and Mercer, 1998). In bioeconomic models related to land degradation, yield response functions in which soil quality is included as a determining variable use soil degradation as a cause of yield decline and erosion is considered as the major process contributing to soil degradation. The analysis of soil degradation as a result of agricultural practices uses macro-nutrient and soil organic matter balances as its measures. Soil (nutrient) loss or reduction in soil depth, considered synonymous with soil quality is assumed to be the main effect. Macro nutrient balances affect soil quality and productivity. Thus, indicates the extent of soil degradation. The use of soil macro nutrient balances (N, P and K) and soil organic matter as soil fertility or quality indicators are discussed in stoorovogel *et al*. (1990). Measuring of nutrient balance in Sub-Saharan Africa (SSA) is well illustrated in the nutrient monitoring model developed by Stoorvogel and Smaling (1990) and revised by Roy *et al*. (2003).

4.6 The State of Research on Land Degradation in Ethiopia

Though the process of human-induced land degradation is a long phenomenon, research undertaking on economics of soil and water conservation and related issues have been limited in Ethiopia. The problem of land degradation and the threat it poses was recognized and development and research efforts to solve the problem of land degradation started in the 1980s and 1990s.

According to Bekele (2003), the first systematic and organized research effort on the problem of land degradation started in the early 1980s when the Soil Conservation Research Project (SCRP) was initiated in different agro-ecological zones in Ethiopia. The SCRP, supported by the government of Switzerland, was initiated and carried out by the Institute of Geography, University of Berne, Switzerland, in collaboration with the Ethiopian Ministry of Agriculture. The focus of soil research activities undertaken has been on the physical, chemical, biological and agronomic properties of soil without much reference to the effect of erosion on these properties and the threat posed on soil productivity from soil erosion. Generally, most of soil conservation studies in the 1980s emphasized on technical solutions to soil erosion problems to the neglect of socioeconomic constraints (Shiferaw and Holden, 1998).

A review of recent literature indicates that two major categories of research on soil and water conservation exist in Ethiopia. The first category deals with behavioural issues related to identifying the social, institutional, cultural, and economic factors that constrained the adoption and dissemination of improved soil and water conservation technologies (Shiferaw and Holden, 1998; Bekele and Drake, 2003; Gebremedhin and Swinton, 2003; Anley *et al*., 2007; Tizale, 2007). The general assertion in this category is that soil conservation is not only a technical problem but also a socio-economic problem, which directed attention to socio-economic and behavioural factors influencing soil conservation decision making.

According to Bekele (2003), this shift in focus from the believe that technological innovations combined with scientific methods were the answers to erosion problems is evident from the ever-increasing literature on factors affecting adoption of improved soil and water conservation technologies (ISWCT) in the high lands of Ethiopia and other developing countries recently. This additional focus helped to understand the complexity of factors influencing land degradation arising from the variation in agro-ecological, socio-economic and institutional factors among small farm households in the highlands of Ethiopia.

The second category of research deals with the application of economic models to estimate the effects of erosion on productivity and income and the cost and benefit of soil and water conservation and provide economic justifications under different time scale (static or dynamic). In this approach, quantifying the effect of soil erosion on crop yield is complex as it involves the assessment of a series of interactions among soil properties, crop characteristics, the prevailing climate, as well as management systems. But this complex task is important to obtain an estimate of the magnitude of the effect in terms of monetary units so that information can be provided to planners and policymakers and to provide the link between physical, chemical, biophysical, agronomic and economic aspects of soil erosion. Important studies that fall in this category include: Sonneveld and Keyzer (2001), Bekele (2003), Holden *et al*. (2005), Tizale (2007)

Using spatial water erosion models that are based on data to adjust future potential yields of the affected areas, Sonneveld and Keyzer (2001) evaluated the implications of soil erosion for future food supply in Ethiopia under alternative scenarios of erosion control, land accessibility, technology levels and non-agricultural sector development. They estimated an agricultural production function with land, labour, and the yield potential as input variables and analyzed the effect of soil and water conservation measures including erosion control and intensified application of agrochemicals. They also apply the production function in an optimization model that maximizes national agricultural revenue under different assumptions with respect to the possibilities for the rural population to migrate to other rural areas with better prospects. The results of their study confirm that an expanding rural labour force, even in combination with the implementation of a soil conservation programme, will not sustain a satisfactory level of food supply. Their result also indicated that rural-to-rural migration from highly populated and degraded areas in the North East and central Ethiopia to productive and less populated areas in the Western and other areas increases the national agricultural revenues and reduce the pressure on land degradation.

Bekele (2003) analysed the optimal path of investment on soil conservation technologies based on a dynamic programming modelling framework and using soil depth as a state variable and soil and water conservation decision (amount of soil depleted) as control variable in the Eastern Ethiopian high lands. He also tried to assess whether soil and water conservation can improve crop yield and farm income. The results of his study indicated that farmers' time preferences affect their conservation decisions. An increase in the discount rate creates disincentive for investment in soil and water conservation. Increase in the market price of grains was found to provide incentive for investment in improved soil and water conservation technologies (ISWCT).

His analysis of the results also suggest that agricultural practices without improved soil and water conservation technologies (ISWCT) yield higher returns per period in the short-term, while practices with improved soil and water conservation technologies (ISWCT) yield higher return per period in the long-term as well as a higher overall return. The present value of returns from soil and water conservation measures increase with an increase in targeted levels of effort in soil and water conservation. However, he also pointed out that the relationship exhibits a diminishing marginal increase in returns as the targeted level of effort in conservation increases.

Holden *et al*. (2005) developed a dynamic bioeconomic model for a severely degraded area, in the central highlands of Ethiopia, with high population density and good market access to assess the impacts of drought on household production and welfare, incorporating land degradation and population growth. The result indicate that land degradation and population growth have increased the need to purchase food over time. Even the combination of soil and water conservation structures with high levels of fertilizer use cannot sustain crop yields as erosion cannot be eliminated and soils in the area are shallow. They suggested that technical change, off-farm income, population control or outmigration is necessary to avoid starvation or chronic dependency on food aid.

Finally, Tizale (2007) used an optimal control model to analyze the dynamics of soil degradation and incentives for optimal management in the central highlands of Ethiopia. In addition to other issues, he estimated the changes of cost of soil erosion over time and the implication of not accounting for soil resource depletion on welfare. He concluded that current practices of farmers involve a net nitrogen nutrient extraction of 16.2 kg/ha from gentle slope lands and 56.7kg/ha from slopping lands entailing a total cost of ETB 255/ha and ETB 928/ha respectively, suggesting that smallholder farmers discount the future heavily, hence overexploit the soil resource base.

CHAPTER FIVE

MODELING PRODUCTION AND LAND MANAGEMENT DECISIONS

5.1 Introduction

In this chapter, a bioeconomic model representing two groups of small farm households in Anjeni area, North Western Ethiopia, is developed. The model focuses on main decisions that can be made by small farm households regarding crop production and land management. The biophysical processes include soil erosion and soil nutrient depletion. The application of soil fertilizers and the use of improved soil and water conservation measures are considered as the major land management technologies.

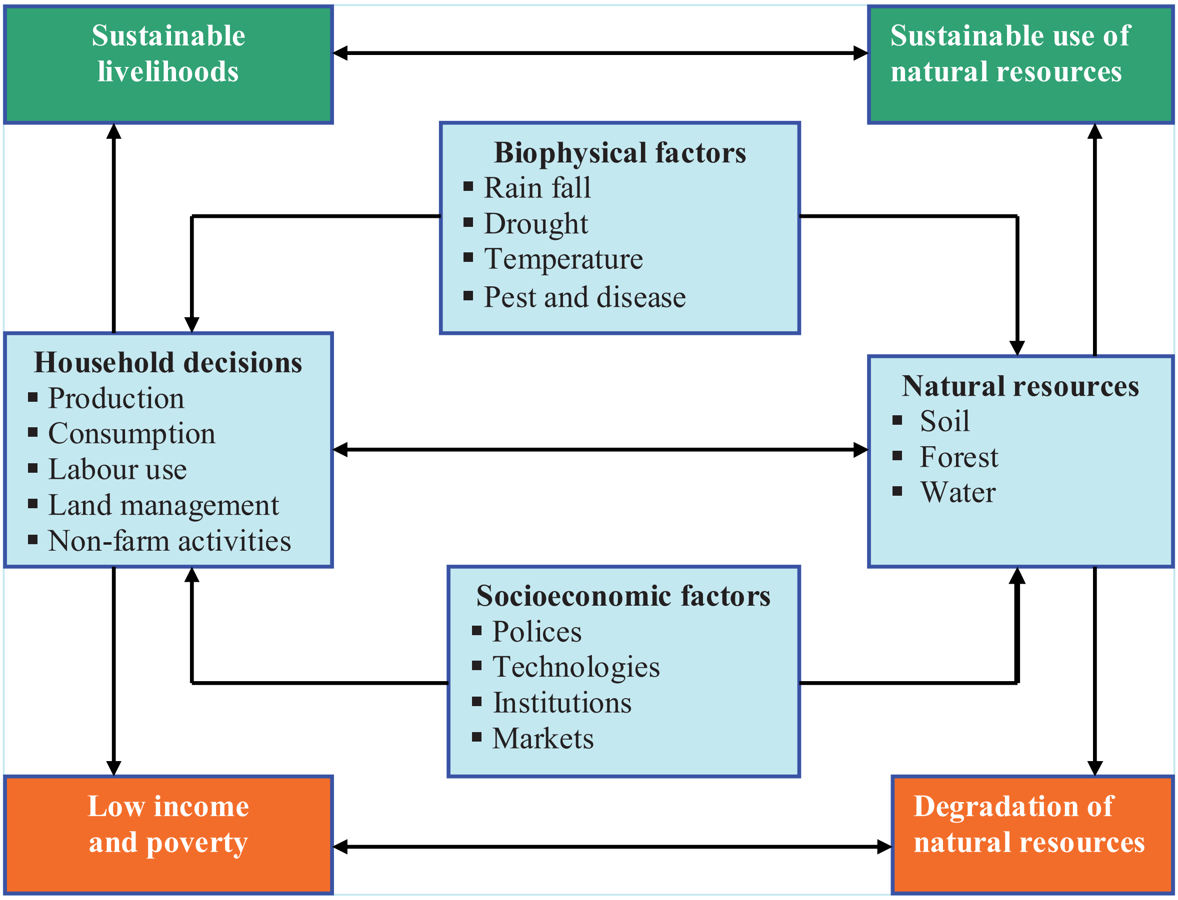
The interaction between biophysical process and socioeconomic conditions is captured by the production function. Soil quality is included as a determining variable in the production function. Soil degradation is considered as a cause of yield decline and erosion is considered as the main process contributing to land degradation. The modified universal soil loss equation (USLE), adapted to the Ethiopian condition, is used to estimate the rate of soil loss from four different land categories to understand the impact of soil erosion on soil nutrient balance and crop yield. Since one of the main objectives of this study is to evaluate the effects of policy incentives and technology interventions on the quality of land in Anjeni area, the Nutrient Monitoring (NUTMON) approach mostly used by FAO is used to assess the soil nutrient balance.

In this study, a linear programming model that maximizes the expected income of small farm households subject to resource and other technical constraints is used as a method for the appraisal of farm households' response to policy incentives and technology interventions. The study also considered down side risk (safety first constraint) associated with rainfall and yield variability. This is because small holder farming in the study area is rain-fed and lack of adequate rainfall (erratic rainfall) often causes yield variability. A positive mathematical programming technique is employed to calibrate the linear programming model to overcome the situation in which the empirical constraint set does not reproduce the base results for lack of an empirical justification, data availability or cost of production.

5.2 Conceptual Frameworks

Figure 5.1 below shows the conceptual framework of a bio-economic model developed to analyze the effect of policy incentives and technology interventions on household income and land management. The conceptual framework of the bio-economic model illustrates the interaction of various exogenous factors with household decisions and the condition of the natural resource base.

Figure 5.1: Conceptual framework of a bioeconomic model



Source: Adapted from Shiferaw (2002)

Farm households set strategies and make production, consumption, labour use and land management decisions. The decision of farm households on land use, crop choice, investment in soil and water conservation technologies and fertilizer use jointly determine the rate of land degradation, productivity and income. Farm households also interact with external environments and their production activities and consumption patterns affect the external environments through possible effects on natural resources in the production process and participation in markets or non-market institutions (Kruseman, 2000; Holden *et al.*, 2005).

The biophysical and socioeconomic environments set boundaries to production possibilities and decision making process of rural households. The link between the livelihood strategies of farm households and natural resources is influenced by biophysical conditions such as rain fall, temperature, pest and disease incidence and socioeconomic factors such as market access, policies, institutions and agricultural technologies. Policy incentives and technology interventions lead to changes in socio-economic environment resulting in different incentives or disincentives for farm households. The type of livelihood strategy adopted and the household production and consumption decisions determine the outcome of the links between livelihoods and natural resource base. The final outcome of the decision making process of the household is reflected in the production pattern, productivity, social well being of the household and impact on natural resources.

5.3 Theoretical Framework

5.3.1 Introduction

The following sections discuss the theoretical concepts and procedures upon which the analytical methods are based for the appraisal of farm households' response to policy incentives and technology interventions. Section 5.3.2 presents the theory of agricultural household model and discusses how different decision problems of farm households can be integrated in to a single household decision problem. In section 5.3.3, the framework of linear programming model that maximizes the expected income of farm households subject to resource and other technical constraints is outlined. Section 5.3.4 presents some concepts related to risk in general and downside risk associated with rainfall and yield variability in particular. Section 5.3.5 describes in detail the technique of positive mathematical programming used to calibrate the linear programming model.

5.3.2 The Theory of Agricultural Household Model

The idea of a household model that links production and consumption decisions dates back to the early twentieth century (Chaynov, 1925 in Yilma, 2005) and has revived latter in the late twentieth century (Singh *et al*., 1986; De Janvry *et al*., 1991; Sadoulet and De Janvry, 1995). Usually a farm household is defined as a group of family members that share the same house or abode. Farm household models assume that there is a single (unified) decision making process in a household regardless of the bargaining power of the household's members in the decision making process.

Today, agricultural household models are the starting point of most microeconomic studies in developing countries by providing a flexible framework for modelling production, consumption and labour supply decisions of farm households (de Janvry *et al*, 1991; Kruseman, 2000; Taylor and Adelman, 2003). As a producer, a farm household maximizes its net revenue or profit with respect to the levels of variable inputs and outputs, given market prices, fixed factors and technology; as a consumer, the household wants to maximize its utility from the consumption of goods subject to constraints determined by market prices, disposable income and other household characteristics; as a worker the household wants to maximize its utility with respect to income and home time (often referred to as leisure) subject to constraints determined by market wage, total time available and worker characteristics.

Unlike the classical economic theory that separate production, consumption and labour supply decisions, agricultural household models integrate, simultaneously, the problems of a household as a producer, as a consumer and as a worker in to a single household decision problem. In general, an agricultural household model can be described as a constrained maximization of utility derived from the consumption of produced goods, purchased goods and endowments. Constraints of the household are commonly reduced to a production function, a household family time endowment, a cash constraint, a fixed amount of land and fixed prices for traded commodities (Taylor and Adelman, 2003; Kupier, 2005). The resulting model is then solved for output supply, input demand, consumption demand, marketed surplus for traded commodities, and prices for non-traded and non-tradable (in case of market failure) commodities (de Janvry *et al*, 1991; Kupier, 2005). Mathematically, the consumption, production and work decision problems of a typical farm household can be integrated in to a single household decision problem as follows. Assuming that the household maximizes its utility (u) from the consumption (C) of produced goods (q), market purchased goods (m) and leisure or home time (l), given household characteristics (z_C) that affect consumption:

(5.1) $$u = u(c_i; z_C);\ \forall i \in q, m, l$$

The objective of the farm household is to maximize its utility subject to the following constraints:

(5.2) $$\sum_{i \in T} p_i c_i \le \sum_{i \in T} p_i (q_i + e_i) + \bar{\pi}$$ Cash income constraint

(5.3) $$q_i = g_i(v, z_q) = 0;\ \forall i \in q$$ Production constraints

(5.4) $$p_i = \bar{p}_i;\ \forall i \in T$$ Effective market prices for tradables

(5.5) $$q_i + e_i = C_i;\ \forall i \in NT$$ Equilibrium condition for non-tradables

(5.6) $$q_i, C_i \ge 0; \forall i \in q, m, l$$ Non negativity constraint

Where p_i and q_i represent the prices and quantities of commodities, e_i is household's initial endowment of commodities, $\bar{\pi}$ is an exogenous income including remittance, v is a vector of inputs and z_q is a vector of household characteristics that influence production. T and NT denote tradable and non tradable goods respectively. The Lagrange function associated with the constrained utility maximization problem can be written as:

(5.7) $$L = u(C_i; z_C) + \lambda_\pi \left(\sum_{i \in T} \bar{p}_i (q_i + e_i - c_i) + \bar{\pi} \right) + \sum_{i \in q} \lambda_{qi} \left(g_i(v, z_q) - q_i \right) + \lambda_{ei} \left(\sum_{i \in NT} p_i (q_i + e_i - C_i) \right)$$

Assuming the existence of an interior solution, the optimal set of quantities (q_i, C_i) and the endogenous prices, $p_i,\ i \in NT$ are given by the solution of the system. The first order conditions of the Lagrange function include:

(5.8) $$\frac{\partial L}{\partial C_i} = \frac{\partial u}{\partial C_i} - \lambda_1 \overline{p}_i - \lambda_{ei} p_i = 0; \forall i \in q, m, l$$ Consumer goods

(5.9) $$\frac{\partial L}{\partial q_i} = \frac{\partial g_i}{\partial q_i} + \lambda_\pi p_i = 0;\ \forall i \in q$$ Producer goods

(5.10) $$\frac{\partial L}{\partial \lambda_\pi} = \sum_{i \in T} p_i C_i = \sum_{i \in T} p_i (q_i + e_i) + \overline{\pi}$$ Full income

(5.11) $$\frac{\partial L}{\partial \lambda_{qi}} = q_i = g_i(v, z_q) = 0$$ Production technology

(5.12) $$\frac{\partial L}{\partial \lambda_{ei}} = q_i + e_i = C_i;\ \forall i \in NT$$ Equilibrium for non-tradables

(5.13) $$p_i = \overline{p}_i; \forall i \in T$$ Market prices for tradables

For tradable goods (T), the decision prices are exogenous given by the effective market prices (farm gate prices). For non-tradable goods (NT), the decision prices are the endogenous shadow prices as determined by the equilibrium between supply $(q_i + e_i)$ and demand (C_i). Tradable and non-tradable goods can be treated symmetrically in the solution of the model by defining an endogenous decision prices, p_i^* as follows.

(5.14) $$p_i^* = \overline{p}_i;\ \forall i \in T\ \ \&\ \ p_i^* = \frac{\lambda_{ei}}{\lambda_\pi};\ \forall i \in NT$$

Where, λ_π is the marginal utility of income given by the cash constraint; λ_{qi} is the marginal utility of output *i*; λ_{ei} is the marginal utility of endowment in non tradable constraint, i given by the equilibrium condition above. If markets for some commodities or labour don't exist, these two sets of decisions are linked through endogenous prices that satisfy the equilibrium conditions between supply and demand in equation (5.12). Endogenous prices indicate the price that households are willing to pay to have the corresponding constraint relaxed by one unit.

This household behaviour can be decomposed in to production and consumption decisions and the reduced form of the model can be written. On the production side, the household, as a producer, behaves as if it were maximizing profit using the p_i^* prices. The household chooses the level of inputs and outputs that satisfy equations 5.9 and 5.11 and the optimum level of outputs and factors yield maximum profit, which is equivalent to maximizing a generalized profit function defined over all tradable and non-tradable commodities. This leads to a system of input demand and output supply (equation 5.15) and a maximum generalized profit (equation 5.16):

(5.15) $q_i = q_i(p_i^*, z_q);\ \forall i \in p$ System of input demand and output supply

(5.16) $\psi = \sum p_i^* q_i$ Generalized profit

On the consumption side, the household as a consumer chooses the level of consumption that maximizes its utility using p_i^* prices under the full income constraint, π^*, expressed in terms of p_i^* prices which leads to a consumption system:

(5.17) $C_i = C_i(p_i^*, \pi^*, z_C);\ \forall i \in q, m, l$ The demand system

(5.18) $\sum p_i^* q_i = \pi^* = \psi + \sum p_i^* e_i + \overline{\pi}$ Full income

According to de Janvry *et al* (1991), although there is no explicit transaction between the producer and the consumer sides of a household and the endogenous prices cannot be observed, these non-tradables' prices play a similar role to tradables' prices in the decision making process of the household. They can serve as indicators of the internal perception of the severity of constraints imposed on the peasant household, i.e., of the level of stress that the household must endure. The external view of the household behaviour is based on its supply and demand responses on the market that exist.

In contrast to the above situation of non-separability, if all markets exist and there is no non-tradable commodity, all prices are exogenous and these decisions can be taken sequentially, as consumption decisions depend on the outcome of the production decisions but not conversely. This is the standard case of separable household model (de Janvry *et al*, 1991).

Market characteristics have significant impacts on production and consumption decisions of farm households. If perfect market exists, where all products and factors are tradable with no (little) transaction costs, all prices are exogenous to the household and the opportunity cost of any product or factor held by the household is its market price. In this case, since all factors are tradable, it makes no difference whether the household uses its own products or its own labour or buy (hire) what it needs to consume.

The assumption of perfect market, where households are assumed to be price takers, results in separability of production behaviour from consumption behaviour. Households behave as if production and consumption or work decisions were made sequentially (Sadoulet and de Janvry, 1995). When separability holds, the household's problems can be solved recursively in two steps. Since consumption doesn't affect prices at the production side, first the production problem is solved by maximizing the profit followed by the consumption problem maximizing utility of the household given the maximum profit obtained from the first step as a link between production and consumption decisions (Singh *et al*., 1986; de Janvry *et al*., 1991; Kupier, 2005).

On the other hand, when there are market failures[1] for some of their products and factors, the good or factor under consideration becomes non-tradable and the effective price of the good or factor used in production and consumption is not exogenous to the household, but is determined endogenously by the household demand and supply conditions (Sadoulet and de Janvry, 1995; Kruseman, 2000; Kuiper, 2005). Its price is no longer determined by the market but internally to the household as a shadow price. In this case the consumption decision affects prices at the production side and there is no longer separability between consumption and production decisions.

[1] Non existence of a market is an extreme case of market failure

5.3.3 Modeling Farm Households' Decisions Using Linear Programming

Full econometric estimation of bio-economic farm household models is very tedious and requires a large and consistent data set. In this study, linear programming technique that has modest data requirement and flexibility is employed to link formulations of farmers' resource management decisions to biophysical features that describe production processes as well as the condition of natural resources to evaluate the effects of policy incentives and technology interventions on sustainable land management and income of small farm households. When farm households are modelled using mathematical programming techniques, the separability assumption is not a necessary condition (Delforce, 1994; Kruseman and Bade, 1998).

Linear programming has been used more extensively to understand household behaviour and, subsequently, to assess policy measures and the effects of technological change (Hazell and Norton 1986). Linear programming models for simulating land degradation have been developed to address agricultural production and environmental concerns in developing countries (Kruseman *et al.*, 1995; Barbier, 1998).

In a linear programming model, the optimal value of an objective function has to be found subject to available resources and other technical constraints. Given the available resources, small farm households in Anjeni area select crop production activities and land management decisions that satisfy farm households' ultimate objectives such as maximizing expected income, improving or maintaining soil quality and avoiding downside risks associated with yield variability due to variability in rainfall amount.

The theoretical concepts and mathematical formulations of downside risk measures (safety first constraints) are described in section 5.3.4 below. The safety first constraint employed in this study selects the farm plan that has an income equal to or greater than some minimal income level, π_0 in every state of nature and maximizes expected income (Low, 1974 in Hazell and Norton, 1986). The linear programming model that maximizes the expected income, $E(\pi)$ of farm households subject to resource and safety first constraints can be written as follows:

$$
(5.19)\qquad
\begin{aligned}
&\underset{x_j}{Max}\, E(\pi) = \sum_{j=1}^{n} pr_t \left(p_j y_{jt} - vc_j \right) * x_j \\
&S.t. \qquad \sum_{j=1}^{n} a_{ij} x_j \le b_i; \qquad i = 1,2,3,\ldots,m \\
&\qquad\qquad \sum_{j=1}^{n} \left(p_j y_{jt} - vc_j \right) * x_j \ge \pi_0; \;\; t = 1,2,3 \\
&\qquad\qquad x_j \ge 0; \qquad j = 1,2,3,\ldots,n
\end{aligned}
$$

Where: $E(\pi)$ denotes expected income, an objective function to be maximized; pr_t is the probability of the different state of nature, t; p_j is the price of output per unit of activity j; y_{jt} is the yield of activity j under the state of nature t; vc_j is the variable input cost per unit of activity j; x_j is the level of activity j; n is the number of possible activities; m is the number of resource constraints; a_{ij} are the technical coefficients or the amount of the i^{th} input required to produce one unit of activity j; b_i is the amount of the i^{th} resources available. Given the assumptions of linear programming, the above model can be solved using Lagrange technique aimed at optimisation problems with constraints.

$$
(5.20)\qquad \underset{X_j,\lambda_i,\lambda_t}{Max}\; L = \sum_{j=1}^{n} pr_i (p_j y_{jt} - vc_j) * X_j + \lambda_i \left(b_i - \sum_{j=1}^{n} a_{ij} X_j \right) + \lambda_t \left(\pi_0 - \sum_{j=1}^{n} (p_j y_{jt} - vc_j) * X_j \right)
$$

The first order conditions to maximize L with respect to activity levels X_j, the shadow prices[1], λ_i for resource i and λ_t for safety first constraints are:

$$
(5.21)\qquad \frac{\partial L}{\partial X_j} = pr_t (p_j y_{jt} - vc_j) - \sum_{j=1}^{n} \lambda_i a_{ij} = 0 \qquad \text{Revenue exhaustion}
$$

Equation (5.21) implies that marginal revenue per unit of activity equals the marginal costs of resources used per unit of activity.

$$
(5.22)\qquad \frac{\partial L}{\partial \lambda_i} = b_i - \sum_{j}^{n} a_{ij} X_j = 0 \qquad \text{Constraints on resource use must hold}
$$

[1] The shadow price of a resource is the amount by which the objective variable of a model increases when the endowment of the resource increases by one unit. It is positive if the resource is fully utilized, zero otherwise

(5.23) $$\frac{\partial L}{\partial \lambda_t} = \pi_0 - \sum_{j=1}^{n}(p_j y_{jt} - vc_j) * X_j = 0$$ Constraints on minimum income level

5.3.4 Production Decision under Risk

5.3.4.1 Introduction

Farmers make decisions in an environment where the outcomes of their decisions are generally unknown. Though agricultural production risks are prevalent in most parts of the world, they are particularly burdensome to small scale farmers in developing countries where most of the agricultural production is dependent on nature, traditional technologies and less developed marketing system (Hazell and Norton, 1986).

In general, variability of yields and prices are the biggest sources of risk. Small scale farming in the highlands of Ethiopia is rain-fed. Lack of adequate rainfall (erratic rainfall) often reduces crop yield. As a result, farmers struggle for their very existence and typically behave in a risk-averse ways and they often prefer production options that can provide a good level of livelihood security. While studying the Risk management strategies of smallholder farmers in the Eastern Highlands of Ethiopia, Legesse (2003) has pointed out that farmers' daily survival of livelihoods motivate them to reduce risks in a limited natural resource arena and boisterous environment and family sustenance is the longstanding concern.

5.3.4.2 Principles of Decision Making under Risk

Both the terms risk and uncertainty are in common usage and there is ambiguity and confusion in the use of these terms in everyday life. Knight (1921) in Hazell and Norton (1986) has distinguished risk and uncertainty on the basis of the knowledge of the possible outcomes of a given decision and on the probabilities of these outcomes. According to this definition, risk is a situation where the probabilities of possible outcomes of a given decision problem are known while uncertainty is a situation where the probabilities of possible outcomes of a given decision problem are unknown.

In a risky environment, many possible outcomes of a given production decision are expected. In such types of environments, the decision problem for a farmer is to rank or order farm plans on the basis of the distribution of outcomes and to select the one that best meets his goal (Hazell and Norton, 1986). According to Berg and Starp (2006), the ordering of risky prospects x_i, which are characterized by their cumulative distributions, $F_i(x)$ requires that an ordinal preference function $\Phi(F_i(x)) \in R$ exists, such that $x_i \geq x_j \Leftrightarrow \Phi(F_i(x)) \geq \Phi(F_j(x))$. The most general approach for comparing risky choices is by means of expected utility $E(u)$ and the preference function based on the utility theory and the distribution of outcome can be defined as follows (Berg and Starp, 2006):

(5.24)
$$\begin{aligned}\Phi(F_i(x)) &= E(u(F_i(x)) \\ &= \int_{-\infty}^{\infty} u(x) f_i(x) dx\end{aligned}$$

Where $u(x)$ marks the utility function, $f_i(x)$ is the probability density function (PDF) and $F_i(x)$ is the cumulative distributive function (CDF). While the expected utility $E(u)$ approach to comparing risky choices is theoretically sound, it has some difficulty in application associated with the selection of the mathematical form of a utility function as well as the quantification of its parameters. Moreover, neither the expected utility nor the certainty equivalent that can be derived from it are easily understood by decision makers (Berg and Starp, 2006).

Hazell and Norton (1986) indicated that utility functions with preferred theoretical properties often have expected values that are difficult to evaluate numerically and higher order polynomials that might be used to approximate more desirable functions can lead to convex programming problems. The need to use a convex programming problem, such as quadratic programming algorithm, is often troublesome, especially if the number of basis changes is large. As a result of this, other concepts such as the value at risk or the expected value variance approach, that belong to the category of risk value models, have been widely used (Berg and Starp, 2006).

5.3.4.3 Downside Risk Measures

Risk measures are based on the intuition that most decision makers, especially subsistence farmers, would be more concerned with negative deviations and focus with an outcome that is worse than some specific target (Yilma, 2005). The risk-value approach, mentioned above, distinguishes explicitly between a risk measure and a measure of value or worth which leads to a preference function based on the trade-offs between risk and worth (Berg and Starp, 2006).

Depending on the distribution of outcome, the riskiness of an alternative is measured based on the moments of distribution around the mean (variance, skewness and kurtosis). In this case, another class of risk measures called 'shortfall measures' is used (Berg and Starp, 2006). Given a minimum target level of outcome, shortfall risk measures consider only the lower parts of the distribution to account for the downside risk and are called lower partial moments (LPM). The lower partial moment of a distribution is defined as follows:

(5.25) $$LPM_{\tau}(z) = \int_{-\infty}^{\pi_0} (\pi_0 - x)^{\tau} f(x)dx; \quad \tau \geq 0$$

Where, τ is the order of the moment, π_0 is a targeted minimum risk reference level of outcome. From, the above function, specific measures of risk can be used by changing the order of the partial moment. These specific measures include: shortfall probability $(\tau = 0)$, shortfall expectation $(\tau = 1)$, and shortfall variance $(\tau = 2)$. In general, the LPM functions asserts that decision makers are risk averse below the target outcome, π_0 and risk neutral above the target outcome (Biglova *et al*, 2005 in Yilma, 2005). On the other hand the expected value is the widely used measures of value or worth in risk-value models. The preference function of risk-value model using the expected value $E(x)$ as value measure and a lower partial moment $\left(LPM_{\tau}(\pi_0)\right)$ as risk measures is defined as follows (Berg and Starp, 2006):

(5.26) $$\Phi(F(x)) = E\left[x\right] - \phi * LPM_{\pi}(\pi_0)$$

Where, $\phi > 0$, denotes the weighting factor and k is the order of the LPM. Increasing ϕ, therefore, means increasing risk aversion.

5.3.4.4 Safety First Model

The risk models considered above are concerned with increasing the value or utility by minimizing a measure of the variability of farm outcome. However many producers, especially small farmers view risk strictly from safety first context (Atwood *et al*, 1988). Safety first models are designed to help farmers insure that they attain the minimum income necessary to meet their production costs and to meet their family living costs (Hazell and Norton, 1986). Given a minimum target level of outcome, the shortfall risk measures of risk-value approach discussed above is similar to the safety first models only when the order of the partial moment is zero (short fall probability).

To address these concerns, several safety first models have been developed. The safety first models are alternative models in which the decision maker is concerned with the probability of failing to achieve his income goals. Various safety first criteria are discussed in the literature. The most commonly used safety first models include Low's safety first model, Roy's safety first criterion, Telser's criteria and the focus loss model. In this study, because of its appropriateness for considering the risk situation of subsistence small holder farmers and its simplicity in application, Low's safety first model is used. According Low (1974) in Hazell and Norton (1986), the safety first model selects the farm plan that has an income equal to or greater than some minimal income level, π_0 in every state of nature and maximizes expected income, $E(\pi)$. The Low's safety first model is specified as follows:

$$\begin{aligned} &\underset{x_j}{Max}\ E(\pi) = \sum_{j=1} E\left(gm_j\right) * x_j \\ &S.t. \qquad \sum_{j=1} a_{ij} x_j \le b_i; \qquad i = 1,2,3,\ldots,m \\ &\qquad\qquad \sum_{j=1} \left(gm_{jt}\right) * x_j \ge \pi_0; \qquad t = 1,2,3 \\ &\qquad\qquad x_j \ge 0; \qquad\qquad j = 1,2,3,\ldots,n \end{aligned} \tag{5.27}$$

Where, $E(\pi)$ denotes expected income, $E(mg_j)$ denotes the expected gross margin of activity j and x_j is the level of activity j, mg_{jt} is the gross margin of activity j under the state of nature t, a_{ij} denotes the resource use coefficient and b_i is the amount of the i^{th} resources available or the resource stocks.

5.3.5 Positive Mathematical Programming

The increasing need to model and simulate behavioural functions under technical, economic and environmental (natural resource) conditions for agricultural policy analysis has strengthened the wide use of Mathematical programming models. However, policy analysis based on normative models that show a wide divergence between base period outcomes and actual production patterns is generally unacceptable (Howitt, 1995). Mathematical programming models are close to a true model, if the decision making process can be adequately represented such that observed production activities can be reproduced or the model replicates the current production program.

Economic analysts prefer mathematical models with a non-linear objective function because responses to policy changes are smooth, unrealistic corner solutions can be prevented and the introduction of flexibility constraints can be avoided. However, the complexity of discretionary policies and large number of heterogeneous production units frequently prevents that non-linear models can be solved in reasonable time or sometimes even at all (Schmidt and Sinabell, 2005).

On the other hand, linear programming models, based on aggregated data suffer from three major problems: first, aggregation of single farm data leads to an aggregation error which usually leads to an overestimation of profits; second, linear programming models tend to over specialize in their results. It is possible to ease this problem to some extent by adding constraints to crop mixes or define a wider array of production choices (for instance by defining varieties of the same cropping activity with modified input use intensities), but these leads into more complicated linear programming models with huge data requirements; third, a linear programming model's endogenous variables use to behave abruptly even when exogenous variables are only slightly modified during simulation.

Even if the model builder manages to exactly replicate the observed activity and resource use levels in his model's base run, small shocks (e.g. price or cost changes) will sometimes lead to completely different production programmes, an 'extinction' of inferior activities, and another overestimation of farm profits. This is because linear programming models have linear production functions, but aggregate supply can usually be shown to be non-linear in inputs and prices which due to various reasons. For instance marginal costs of producers entering a market at a high price level are usually higher than those of suppliers who start offering at lower price levels. In addition to this, as agricultural production is based on complex interlinked biological processes which are non-linear in nature the linear model might be an oversimplification even on the farm level. The model thus underestimates the endogenity of certain coefficients driving the results. Put more generally, the linear model is said to be not fully specified, meaning that resource constraints might be missing or not be reflected in sufficient detail, and that information on available technologies are missing too (Howitt, 1995; Hazell and Norton, 1986).

There are several ways to correct linear programming problems, given a more realistic expression of the representative agents' choice and constraints. Imposing upper and lower bounds to production levels as constraints and the use of crop rotation constraints to curtail over specialization of production activities have been used to solve the aggregation and calibration problems in linear programming (Howitt, 1995). Hazell and Norton (1986) suggested, among other criteria, a marginal cost test to ensure that marginal costs of production, including the implicit opportunity cost of fixed inputs, are equal to the output prices and a comparison of the dual value on land with actual rental value to validate the model. The calibration problem can be mathematically defined in a situation when the number of binding constraints in the optimal solutions is less than the number of non-zero activities observed in the base solutions. However, if the there is enough data to specify a constraint set to reproduce the optimal base year solution, the additional model calibration will be redundant.

This section presents a methodology called positive mathematical programming (PMP) developed by Howitt (1995) to calibrate a linear programming model to overcome the situation in which the empirical constraint set does not reproduce the base year results for lack of an empirical justification, data availability or cost of production at different levels. This method transcends the linear programming framework in that it introduces an artificial cost effect of the missing elements with the help of a non-linear variable cost (yield) function (Howitt, 1995). This is going to change the linear programming into a non-linear programming (NLP) problem and is commonly called Positive Mathematical Programming.

The methodology of PMP relies on the assumption that an observed production activities' allocation of a farm or a region is the consequence of profit maximizing behaviour (Schmid and Sinabell, 2005). PMP is a method used to calibrate mathematical programming models to observed behaviours during a reference period by using the information provided by the dual variables of the calibration constraints (Howitt, 1995). The dual information is used to calibrate a non-linear objective function such that the observed activity levels are reproduced for the reference period but without the calibration constraints. Observed average cost are used in three step procedure to derive additional unobservable cost which are compressed in to parameters of a non linear optimization model (Howitt, 1995; Schmid and Sinabell, 2005).

The procedure in PMP follows three specific steps (Howitt, 1995): The first step consists of writing a linear programming model as usual but adding to the set of limiting resource constraints a set of calibration constraints that limit the activities to the observed levels of the reference period. The constrained linear programming model is used to generate particular dual values. In the second step of the PMP, the duals from the first step are used to calibrate the parameters of the non-linear objective function. In this particular case, we calibrated the parameters of a variable cost function that has quadratic functional form, holding constant variable input prices at the observed market level.

The third step of PMP uses the calibrated non-linear objective function in a non linear programming problem similar to the original one except for the calibration constraints, i.e., the cost parameters are used with the base line data to specify the PMP model. This calibrated non-linear model is consistent with the choice of the non-linear activity cost function derived in the preceding step and exactly reproduces observed activity levels and original duals of the limiting resource constraints. The resulting model calibrates exactly to the base year solution and original constraint structures.

The Algebraic Form of Positive Mathematical Programming (PMP) Model

The objective of a farm household is to maximise its income from the production of crop and non-farm activities involving different management practices. The model assumes that crop production costs are non-linearly increasing in outputs. The model also consists of factor uses and other technical characteristics of production, observed crop mixes and resource endowments. Land allocation to major crops in the study area is the resource pattern that needs to be reproduced in the base run of the model.

The idea of PMP is twofold: first it makes marginal income (profit) from activities a non-linear function of resources employed in these activities. This solves the problem of erratic linear programming model behaviour. Second, it calibrates the functional parameters of the newly introduced non-linear terms such that the base resource allocation is exactly replicated. This solves the problem of the divergence between normative results and observed reality in linear programming models. Consider the following non linear objective function of a PMP model where the parameters of the variable cost functions has a quadratic functional form:

$$\underset{X_j}{Max}\ \pi = \sum_{j=1}^{n}(MR_j - MC_j)X_j - \underbrace{\sum_{j=1}^{n} ac_j X_j - \tfrac{1}{2}\sum_{j=1}^{n} bc_j X_j^2}_{\text{PMP-term, non-linear in X}}$$

(5.28)

$$s.t.$$

$$\sum_{j=1}^{n} a_{ij} X_j \le b_i$$

$$X_j \ge 0$$

Where: π is an objective function (income), MR_j represent the marginal revenue; MC_j is marginal cost; X_j is production activity levels; b_i denotes the available resources; a_{ij} are resource use coefficients; ac_j is the constant in the nonlinear cost item ; bc_j is the slope of the nonlinear cost item; λ is the marginal opportunity cost of resources (Shadow values); γ_j are the duals associated with the calibration constraints. The Lagrange function can be written as follows:

(5.29) $$L = \sum_{j=1}^{n}(MR_j - MC_j)X_j - \sum_{j=1}^{n} ac_j X_j - \tfrac{1}{2}\sum_{j=1}^{n} bc_j X_j^2 - \left[\sum_{i=1}\lambda_i\left(\sum_{j=1}^{n}\left(a_{ij}X_j\right) - b_i\right)\right]$$

The Kuhn-Tucker[1] conditions, thus, are:

(5.30) $$\frac{\partial L}{\partial X_j} = (MR_j - MC_j) - ac_j - bc_j X_j - \sum_{i=1}^{n} \lambda_i a_{ij} \leq 0 \qquad \perp \quad X_j \geq 0$$

which can be rearranged to reflect the revenue exhaustion assumption that marginal revenue (MR) is equal to marginal cost (MC), composed of marginal accounting cost, the derivation of the PMP-term with respect to x (marginal non-linear cost), and the marginal opportunity cost of resources employed (last RHS element in equation 5.31):

(5.31) $$MR_j = MC_j + \left(ac_j + bc_j X_j\right) + \sum_{i=1}^{n} \lambda_i a_{ij}$$

The PMP term is designed such that 'unobserved' costs increase with deviations from the base area in both directions. This is achieved by calibrating the values of the constant *ac* and the slope bc such that the base area is exactly matched in the base solution. The calibration of the parameters of the PMP-term in the objective function can be carried out on the basis of inherent point elasticities[2] (ε_{gm}) of area with respect to gross margins and their conversion into inverse area elasticities:

(5.32) $$\varepsilon_{gmj} = \frac{\partial X_j}{\partial MR_j} \frac{MR_j}{X_j} \Leftrightarrow \frac{1}{\varepsilon_{gmj}} = \frac{\partial MR_j}{\partial X_j} \frac{X_j}{MR_j}$$

Thus, by further differentiating the first order conditions of the initial optimisation problem with respect to x and multiplying with (x / MR), we get[3]:

(5.33) $$\frac{1}{\varepsilon_{gmj}} = \frac{\partial MR_j}{\partial X_j} \frac{X_j}{MR_j}$$

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[1] The Kuhn-Tucker conditions are necessary and often sufficient conditions for an optimum solution when non-negativity constraints are involved with the model. The complementary slackness is symbolized by the sign "⊥", which states that not both the partial derivative and the non-negative variable can be non-zero, which is also expressed by the product of these two elements in the end. Nevertheless, the Kuhn-Tucker conditions do not rule out that both elements are zero.

[2] Even though the quadratic cost function representing PMP is non-linear, the implicit supply elasticities are still point elasticities. The supply function implicit in a standard PMP model is not a constant-elasticity function. This implies that the further we move up the supply curve (north-east, higher prices and quantities), the less elastic supply becomes with respect to price, whereas when we move downwards (south-west, lower prices and quantities), the more elastic quantity supply reacts to price changes.

[3] Elasticity of y with respect to changes in x is defined as $\frac{dy}{dx} \cdot \frac{x}{y}$

(5.34) $$\frac{1}{\varepsilon_{gmj}} = \frac{\partial\left(MC_j + ac_j + bc_j X_j + \sum_{i=1}^{n} \lambda_i a_{ij}\right)}{\partial X_j} \frac{X_j}{MR_j}$$

(5.35) $$\frac{1}{\varepsilon_{gmj}} = bc_j \frac{X_j}{MR_j}, \quad \Rightarrow bc_j = \frac{1}{\varepsilon_{gmj}} \frac{MR_j}{X_j}$$

This means that we can impute a value for the elasticity ε_j and simply calculate bc_j using observed gross margins and activity levels. The values for elasticities may be taken, a-priori, from own statistical estimations or from secondary sources. However, because of lack of time series data on the supply and prices of crop in the study area, the values of supply elasticities were taken from secondary sources. The calculation of ac_j is then possible by using equation (5.31), since the marginal opportunity costs of other resources are reflected in their shadow prices in the optimization model. This is technically achieved by carrying out an initialisation run where the activity levels are closely bounded to the observed values, but not fixed. The method is demonstrated in the General Algebraic Modelling System (GAMS) software. If there is minimal slack for activity levels, the initial run (still an LP without the PMP terms) will return realistic resource constraints for land and labour which then can be used to calibrate ac_j.

5.4. Empirical Specifications and Estimations

5.4.1 Objective Function

An objective function is a function for which an optimal value has to be found subject to resource and other technical constraints. In this study, the objective function maximizes expected household income derived from agricultural products and off-farm income while accounting down side risk associated with rainfall and yield variability. The objective function that maximizes expected income and accounts for down side risk associated with rainfall and yield variability is specified as follows:

(5.36) $$Max : E(\pi) = \sum_{c} E(gm_{(c,s,sc,f)}) * x_{(c,s,sc,f)} - \sum_{m=1}^{12} w_m^h * x_m^h + \sum_{m=1}^{12} w_m^o * x_m^o$$

Where $E(\pi)$ is the expected income; $E(gm_{(c,s,sc,f)})$ is the expected gross margin; $x_{(c,s,sc,f)}$ is the level of crop type, c on soil type, s under soil conservation status, sc with fertilizer, f ; $x_m^h \& x_m^o$ are respectively, monthly labour hiring activity and off-farm activities; $w_m^h \& w_m^o$ are, respectively, wage rates for hired labour and off-farm labour.

5.4.2 Crop Yield Functions

The model offers choices from four major crops grown in Anjeni area: *Teff*, Barley, Wheat and Horse Bean. Yield functions are specified for each crop type. Since rainfall is uni-model and there is no irrigation, all crops are produced waiting the rainy season. The most commonly used functional forms to analyze input and crop yield relationships include: Cobb-Douglas, quadratic, square root and transcendental logarithmic (Translog).

Different criteria are used to select among these functional forms. Theoretical consistency, factual conformity, flexibility and ease of computation are usually used as criteria for selecting a given functional form. In addition to these, the choice of a functional form may also depend on the research question and the underlying production process to be modelled (Sadoulet and de Janvry, 1995). This implies that there is no one single best production function for all purposes and the different functional forms may be well suited for specific applications but not for all purposes.

Generally, the objective of this analysis is to choose a functional form that can represent the relationship between crop yield, soil nutrient and labour inputs in production. In this study, Cobb-Douglas production function is used to specify crop input and output relationships. Cobb-Douglas production function is a well behaved production function and some empirical results confirm its theoretical validity and it has been widely used to represent crop response to applied soil nutrients because of its convenience in estimation and interpretation of parameters (Tesfamicael, 2005; Tizale, 2007). After log-transforming, the Cobb-Douglas functional form is written as follows:

(5.37) $$\ln y = \beta_0 + \beta_1 \ln(L) + \beta_2 \ln(N) + \beta_3 HYV + \beta_4 S + \beta_5 sc + \gamma$$

Where; y is yield; β_0 is a constant, L and N are respectively labour input (man days/ha) and soil nutrient (nitrogen) input (kg/ha); HYV, S, and sc are dummy variables, respectively, for the use of high yielding variety (only for Wheat), soil type and the use of improved soil and water conservation technologies; $\beta_1, \beta_2, \ldots, \beta_5$ are the (partial) elasticity of output with respect to labour, nitrogen, improved seed, soil type and improved soil and water conservation structures. They measure the percentage change in output for, say, a 1 percent change in inputs either labour or nitrogen or they measure a percentage change in output for a shift in the dummy variables from 0 to 1; γ is the stochastic disturbance term. The descriptions of the four major cereal crops in the study area are presented in table 5.1.

Table 5.1: Description of variables used in the yield functions

Variables	*Teff*		Barley		Wheat		Horse Bean	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Yield (kg/ha)	1175.6	449.65	1387.73	370.22	1847.57	579.11	1010.86	342.16
Labour (md/ha)	104.3	28.83	41.74	8.58	78.85	15.20	34.47	8.26
Fertilizer,N (kg/ha)	29.9	14.81	24.46	10.65	29.94	11.97	0.00	0.00
Seed:1 HYV; 0 otherwise	0.0	0.00	0.00	0.00	0.59	0.49	0.00	0.00
SC: 1 conserved; 0 otherwise	0.52	0.501	0.47	0.50	0.57	0.49	0.36	0.48
Soil type (S): 1 black/brown; 0 otherwise	0.44	0.45	0.36	0.48	0.08	0.07	0.248	0.50
Observations	178		261		138		86	

Source: Own survey (2007)

Cobb-Douglas estimates of yield functions for four major crops are presented in table 5.2 and 5.3 below. The Cobb-Douglas yield function is estimated relating crop yield of *Teff*, Barley, Wheat and Horse Bean to labour input, fertilizer, soil type, and the presence of soil and water conservation structures. Improved seed variety is included in Wheat yield function. The Cobb-Douglas functional form did provide a good fit to the yield functions.

The null hypothesis that the coefficients in the model are jointly zero is rejected in all cases. The overall F-test is significant at 0.01 level and all variables are positive and significant. The adjusted R^2 are high showing that the variables included in the yield functions explained more than 75% of the variations in the yield levels for *Teff*, Barley and Wheat, and more than 50% of the variations in the yield levels for horse Bean. Labour and soil fertilizer explained most of the variation in crop yields. Both improved soil and water conservation measures and the nature of the soil have influenced crop yield. The variations between yields with and without the application of physical soil and water conservation measures may be associated with the effect of conservation measures on moisture retention in the soil rather than its effect on soil depth.

Table 5.2: Cobb-Douglas estimates of yield functions for *Teff* and Barley

Variables	*Teff*				Barley			
Iny	Coef.	Std.Err.	t-value	P>|t|	Coef.	Std.Err.	t-value	P>|t|
Constant	4.090	0.248	16.45	0.000	5.700	0.131	43.56	0.000
InL	0.373	0.064	5.845	0.000	0.146	0.038	3.84	0.000
InN	0.342	0.026	13.10	0.000	0.289	0.016	18.49	0.000
S	0.100	0.032	3.14	0.002	0.135	0.018	7.54	0.000
sc	0.088	0.032	2.77	0.006	0.048	0.017	2.75	0.006
Adj.R²	0.799				0.796			
F-value	176.5				255.24			
Prob >F	0.000				0.000			
Observ.	178				261			

Table 5.3: Cobb-Douglas estimates of yield functions for Wheat & Bean

	Wheat				Horse Bean			
Iny	Coef.	Std.Err.	t-value	P>|t|	Coef.	Std.Err.	t-value	P>|t|
Constant	4.399	0.372	12.02	0.000	5.074	0.396	12.81	0.000
InL	0.430	0.098	4.558	0.000	0.468	0.114	4.108	0.000
InN	0.321	0.038	8.757	0.000	-	-	-	-
S	0.058	0.062	1.004	0.317	-0.156	0.066	-2.37	0.020
SC	0.053	0.036	1.439	0.153	0.492	0.066	7.470	0.000
HYV	0.175	0.372	4.475	0.000	-	-	-	-
Adj.R²	0.788				0.503			
F-value	102.988				29.654			
Prob>F	0.000				0.000			
Observ.	138				86			

Incorporating the Yield Function in to Linear Programming

To incorporate the yield functions in to linear programming framework, linear approximations of the non-linear functions are made. The linearization of the functions is obtained using the first order approximation of their Taylor expansion around the optimum values of labour (L^*) and fertilizer (N^*) inputs by dropping the reminder. Based on Taylor expansion techniques, If $f(L,N)$ is a differentiable function with real values, one can approximate $f(L,N)$ for (L,N) close to $f(L^*,N^*)$ by the formula:

(5.38) $$f(L,N) \approx f(L^*,N^*) + \frac{\partial f}{\partial L}(L^*,N^*)(L-L^*) + \frac{\partial f}{\partial N}(L^*,N^*)(N-N^*)$$

Considering the above Cobb-Douglas yield function and the optimum values of labour and fertilizer, Taylor expansion technique can be used to estimate the linear approximation as follows:

(5.39) $$\begin{aligned} f(L,N) &\approx \beta_0 L^{\beta_1} N^{\beta_2}(L^*,N^*) + \beta_0\beta_1 L^{(\beta_1-1)} N^{\beta_2}(L^*,N^*)(L-L^*) \\ &+\beta_0\beta_2 L^{\beta_1} N^{(\beta_2-1)}(L^*,N^*)(N-N^*) + \beta_3 HYV + \beta_4 S + \beta_5 SC \end{aligned}$$

5.4.3 Resources and Constraints

5.4.3.1 Land Classes

Uniform treatments of land in some models do not reflect the quality and productivity of soil on different land classes as well as the different type of efforts needed for land management such as soil conservation, fertilization and other related activities. To relax the strong assumption of treating different land types as having uniform characteristics, land in Anjeni area is classified in to four land classes depending on the slope of farm plots and colour of the soil. The land constraint is specified in equation 5.40 and the criteria used to classify land types in Anjeni area are presented in table 5.4.

(5.40) $$\sum_{j=1}^{n} X_{js} \le S_s$$

Where, x_{js} denotes the level of activity j on land class i, and S_s is the total area of land available under land class s

Table 5.4: Land class depending on slope and colour of soil

Land class	Slope gradient (%)	Soil colour
S_1	Flat-gentle (0-15)	Red
S_2	Flat-gentle (0-15)	Black/Brown
S_3	Steep(15-45)	Red
S_4	Steep(15-45)	Black/Brown

5.4.3.2 Labour for Production and Conservation

Labour is required for ploughing, weeding and harvesting of crops and for the construction of soil and water conservation measures. Labour demand varies from one month/season to the other implying that it is important to put labour constraint for each month. The number of days available for various economic activities is a constraint for a farm household.

Parameters related to labour use were estimated based on the family size, age and sex composition of sample households. The number of days a rural household can undertake agricultural activities in each month is limited by religious holidays as well as Sundays and Saturdays. This requires adjustment to the total number of days available in one year. However such constraints do not apply to non-farm activities

Construction of improved soil and water conservation measures also requires considerable amount of labour input, however it can be undertaken any time of the season. The distance between soil conservation structures is determined by the slope of farm plot. This distance determines the amount of labour required per hectare to construct soil and water conservation structures. The Ministry of Agriculture and Rural Development in Ethiopia has developed work norms and technical standards such as base width, height and length of different soil and water conservation structures. Based on this, labour requirement for the construction of soil bunds, stone bunds and *fanaya juu* are respectively 150 person days per kilometres(PDs/km), 250PDs/km and 200 PDs/km (MOARD, 2005).

The distance between soil and water conservation structures depend on the slope of the farm plot. The steeper the slope, the closer the spacing between soil and water conservation structures, hence the length of soil conservation structures per hectare is greater for steeper slopes. MOARD (2005) has set the minimum base width to be 1 meter for soil bund and *fanaya juu* and 0.6 meter for stone bund. The length and area covered with soil and water conservation measures (ha/ha) and the Labour requirements for improved physical soil conservation structures are presented in Appendix-3 and Appendix-4 respectively. The total household time endowment is estimated after sufficient time has been deducted for non-farm activities, resting time and adjusting religious holidays (non-working days) in each month. The household labour constraint is given by the following equations:

(5.41) $L_f + L_o + L_l \leq \overline{L}$ Family labour constraint

(5.42) $L_c + L_{sc} \leq L_f + L_h$ Total on-farm labour constraint

(5.43) $L_o \leq \overline{L}_0$ Off-farm labour constraint (off-farm jobs are limited)

(5.44) $L_l \geq \overline{L}_l$ Minimum home time constraint

Where: $L_f, L_o, L_l, \overline{L}, L_h, L_c, L_{sc}, \overline{L}_0, \overline{L}_l$ denote, respectively, family labour used on-farm, family labour used off-farm, home time (leisure), total household labour endowment, hired labour, labour used for crop production, labour used for soil conservation, maximum level of off-farm labour and minimum level of leisure time requirement. Table 5.5 shows how the labour and land constraints are incorporated in to the linear programming matrix. Four different land classes, S_s are incorporated in to the model. Off-farm jobs are limited and vary from season to season; hence off-farm labour supply is constrained.

Table 5.5: Linear programming tableau for land and labour constraints

	Teff Prod. (ha)	Barley Prod. (ha)	Wheat Prod. (ha)	H/Bean Prod. (ha)	Soil & water Conserv. (m/ha)	Home time (leisure) (M)	Family labour (M)	Hire labour (M)	Sell Labour (M)	RHS
Objective function	$+gm$	$+gm$	$+gm$	$+gm$	0	0	0	$-w^h$	$+w^o$	Max.
Land	+1	+1	+1	+1	0	0	0	0	0	$\leq S_s$
Labour	$+L_c$	$+L_c$	$+L_c$	$+L_c$	$+L_{sc}$	+1	-1	-1	+1	≤ 0
Leisure requirement	0	0	0	0	0	+1	0	0	0	$\geq \overline{L}_l$
Off-farm Labour	0	0	0	0	0	0	0	0	+1	$\leq \overline{L}_0$

5.4.3.3 Consumption Constraint

The simplest and straight forward way to account for household consumption requirements in programming models is to impose a lower bound constraint on the production of required food crops (Yilma, 2005). However this approach doesn't allow the level of consumption to vary with the level of household income and other non-income factors, such as family size. The alternative and theoretically sound approach is to derive a set of demand functions from utility functions (Yilma, 2005).

The estimation of demand equation parameters uses the theory of demand as a guide line for the choice of functional forms and variables to be included. The theory of consumer behaviour explains how a rational consumer chooses what to consume when confronted with various prices and a limited amount of income. Maximizing the utility function subject to a given budget constraint yields the demand function.

Assuming that the utility function of a household is $u(C; z_C)$, where C is a vector of quantities of n consumption goods and z_C are household characteristics that influence consumption. If the amount of income to be spent is π, its budget constraint becomes $\pi = P'C$, where P is a vector of prices. Therefore, the objective of the household is to maximize its utility subject to its budget constraint:

(5.45) $$\begin{aligned} &Max\ \ u(C; z_C) \\ &s.t \\ &P'C \le \pi \end{aligned}$$

The Lagrange function can be written as:

(5.46) $$Max\ \ u(C; z_C) + \lambda_\pi(\pi - P'C)$$

Where, λ_π is a Lagrange multiplier that measures the marginal utility of income. The solution to this maximization problem is a set of *n* demand equations with income, own price, price of other goods and household characteristics as its arguments.

(5.47) $$C_i = c_i(p, \pi, z_C);\ i = 1, 2, ..., n$$

These n demand equations will then contain $n^2 + n$ independent parameters (n income elasticities, n own price elasticities and $n^2 - n$ cross price elasticities). However, there are a number of constraints that these parameters must satisfy which allow a substantial reduction in the number of parameters to be estimated and hence reduces the amount of data needed for estimation purpose. These constraints include: the Engel equations, the cournot equations, the Euler equations, the slutsky equations. Using these restrictions the (n^2+n) parameters of the demand system can be reduced to $1/2(n^2+n-2)$.

For empirical work, time series data are needed to observe price changes and estimate price elasticity. Cross-sectional data from small geographical locations have limitation in the estimation of demand systems because they lack the necessary variability in price data. However, in most cases, time series data are not available. In this situation the commonly used approach is to estimate Engel curve and generate the necessary parameters such as income and price elasticities from the estimated Engel curves. For cross-sectional data in which income variation is large and price variation is small, Engel curves represent a fast and clear way to depict the relationship between the driving variable, income, and the choice variable, consumption.

Estimating Engel Functions

In situations where only cross-sectional data are available, we are limited to the estimation of Engel curves. Engel curves relate quantity consumed, C_i, to income, π, given household characteristics, z_C and a constant price, p_i. Engel curves show how consumption patterns vary between households at different income levels.

(5.48) $$C_i = C_i(\pi; z_C);\ i = 1, 2, ..., n$$

The desirable properties of Engel curves include the following (Sadoulet and de Janvry 1995): first, they should satisfy the budget constraint (predicted expenditure for each commodity should add up to total expenditure); second, they should be able to represent different categories of goods (luxuries, necessities and inferior goods); third, they should have variable income elasticities due to the fact that income elasticities tend to decline as income increases; fourth, the consumption of many commodities should reach a saturation point as income increases.

The most commonly used forms of Engel functions include: Linear, double logarithmic, semi-logarithmic and logarithmic reciprocal. With respect to the above desirable properties, only the linear form satisfies the Engel aggregation equation. Except for the double logarithmic form, all other have variable elasticities. In this study the linear Engel function is estimated and the corresponding income elasticities are derived as follows:

(5.49) $$C_i = \beta_0 + \beta_1 \pi$$ Engel equation

(5.50) $$\varepsilon_\pi = \frac{\beta_1 \pi}{\beta_0 + \beta_1 \pi}$$ Income elasticity

(5.51) $$\varepsilon_{ii} = \frac{1}{\omega}\varepsilon_{\pi i}\left(1 - w_i \varepsilon_{\pi i}\right) - w_i \varepsilon_{\pi i}$$ Own price elasticity

(5.52) $$\varepsilon_{ij} = -\frac{w_j}{\omega}\varepsilon_{\pi i}\varepsilon_{\pi j} - w_j \varepsilon_{\pi i},\ i \neq j$$ Cross price elasticity

Where, $\omega = (\partial \lambda_\pi \pi)/(\partial \pi \lambda_\pi)$ is the flexibility of money and w_j is the budget share of good i (Sadoulet and de Janvry, 1995). Table 5.6 presents a descriptive statistics of household expenditure. Cereals, mainly, Barley, Wheat, *Teff* and Horse Bean are the major food consumption items to meet energy requirements of small farm households in most highlands of Ethiopia, hence, take the major share of total household expenditure in Anjeni area. Major non food consumption expenditure includes clothing, kerosene, salt, sugar and expenditure on education and health services. The average expenditure of households is about ETB 5591.50.

Table 5.6: Descriptive statistics of household consumption expenditure

Expenditure	Mean	std. dev.	% of cereal expenditure
Teff expenditure (ETB)	1632.30	1563.50	47.8
Barley expenditure (ETB)	650.85	789.70	19.1
Wheat expenditure (ETB)	635.70	1105.10	18.6
Bean expenditure (ETB)	495.30	688.20	14.5
Cereals expenditure (ETB)	3414.20	1860.80	---
Total household expenditure(ETB)	5591.50	2240.90	---
Household size	5.59	1.92	---

Source: Own survey (2007)

The average expenditure on major cereals is about ETB 3414.20 among which *Teff* constitutes of nearly half of the expenditure share. Based on the information collected from households and market, the empirical specification of the Engel curves are given by the following equations:

(5.53) $$C_i = \beta_{0i} + \beta_{1i}E + \beta_{2i}H + \gamma_i$$

Where, C_i is the quantity of food crop, i consumed in kg, E is the household expenditure, H is the average household size, $\beta's$ are parameters to be estimated and γ_i is the error term.

Finally, four major food crops produced and consumed by the households are used to estimate the Engel curves presented in table 5.7. The income elasticities range from 0.63 for Barley, to 1.81 for horse Bean. *Teff*, the most preferable staple food at the national level that could fetch higher prices for farmers relative to the other food crops and a crop with very high domestic demand, has income elasticity greater than one. This is consistent with the fact that consumption of *Teff* is considered by many poor farmers as a luxury. Most farmers don't consume *Teff* as they prefer to sell it and buy Barley, Wheat and/or other commodities for consumption. High income elasticities for *Teff* and horse Bean may imply that demand for *Teff* and horse Bean will increase and farmers may shift towards producing these crops, if their income increase due to technology and policy interventions and improved marketing system. The linear programming tableau for consumption and safety first constraints are shown in Table 5.8. The linear programming model maximizes the objective function subject to consumption constraints and some minimum level of income, π_o.

Table 5.7: Engel functions estimated for major food crops

	Teff	Barley	Wheat	Horse Bean
Constant	-12.697	39.871	39.877	-22.533
E(ETB)	0.056 (1.04)	0.012 (0.63)	0.028 (0.80)	0.009 (1.81)
H	-6.166	5.5346	-13.832	11.713
Adj.R^2	0.23	0.028	0.068	0.063
Prob >F	30.059**	3.860*	8.103**	7.582**
F-statistics	0.000	0.023	000	000
Observations	196	196	196	196

Note: * and ** denote significance level at 0.01 and 0.05 probability levels and numbers in the bracket are income elasticities

Table 5.8: Linear programming tableau for consumption and safety first constraints

	Teff Prod. (ha)	Barley Prod. (ha)	Wheat Prod. (ha)	H/Bean Prod. (ha)	Sell Crop	buy Crop	crop Consum.	Income (ETB)	RHS
Obj. fun. (ETB)	$+gm$	$+gm$	$+gm$	$+gm$	$+p$	$-p$	0	0	Maximize
Income identity (ETB)	$+gm$	$+gm$	$+gm$	$+gm$	$+p$	$-p$	0	+1	$=\pi$
Crop balance (kg)	+1	+1	+1	+1	-1	+1	-1	0	$=0$
Consumption requirement (kg)	0	0	0	0	0	0	+1	$-b$	$\geq \beta_0$
Expected Income	0	0	0	0	0	0	0	+1	$\geq \pi_0$

5.4.3.4 Cash and Credit Constraints

Sufficient and timely access to credit is crucial for small farm households who have little or no own financial resources. However, shortage of financial resources or lack of credit is one of the major constraints facing small farmers in Anjeni area. The main sources of cash to farm households include cash from the sale of crop, livestock and off-farm income. Farmers do not have access to formal credit from the commercial bank of Ethiopia and other private banks due to lack of collateral.

Although farm households do not get credit from banks, the possibility of access to credit for small farmers is included in the model. Because limited amount of short term fertilizer credit is provided to selected farmers by the government through agricultural cooperatives and other microfinance institutes. Specifically, the Amhara Credit and Saving Institute (ACSI), operating in Amhara region, provides limited amount of credit for one production season. Given an interest rate, *r*, the cash, credit and fertilizer constraints can be specified in the following equations:

(5.54) $$\sum_{j=1} a_j X_j + \sum_{m=1} w^h X_m^h - \sum_{m=1} w^o X_m^o \leq X_k + K$$ Cash constraint

(5.55) $$\sum_{j=1} (a_{fj} X_j) \leq F_f ; \forall f \in F_f$$ Fertilizer balance

(5.56 $$K \leq \overline{K}$$ Credit constraint

Where, X_j denote production activities and a_j and a_{fj} denotes, respectively, the amount of cash cost required to produce a hectare of the j^{th} crop production activity and a unit of fertilizer type f required to produce a hectare of j^{th} crop activity; F_f is the amount of fertilizer type f; X_m^h and X_m^o denotes, respectively, the monthly labour hiring and the monthly off-farm activities; P_f, w^h and w^o are respectively the price of fertilizer, f ,and the average wage rate for hired labour and the average wage rate for on-farm labour respectively; X_k, K, and $\bar{K}$ are respectively, the total available own fund in ETB, the amount of credit and the maximum amount of cash available from credit (credit limit) for a household.

Table 5.9: Linear programming tableau for credit and fertilizer constraints

	Activities						RHS
	Teff Prod. (ha)	Barley Prod. (ha)	Wheat Prod. (ha)	H/Bean Prod. (ha)	Borrow credit (ETB)	Buy fert. (kg)	
Obj.function (ETB)	$+gm$	$+gm$	$+gm$	$+gm$	$-r$	$-p_f$	Max.
Fertilizer balance (kg)	$+F_f$	$+F_f$	$+F_f$	$+F_f$	0	-1	≤ 0
Credit limit (ETB)	0	0	0	0	+1	0	$\leq \bar{k}$

5.4.4 Biophysical Processes: Soil Erosion, Conservation and Nutrient Balance

5.4.4.1 Estimating Soil Erosion and Soil Conservation

Soil erosion is influenced by different factors. The major factors influencing soil erosion include: topography (slope length and slope gradient), rainfall, soil type, land cover and land management practices. To understand the impact of soil erosion on soil nutrient balance (soil quality) and crop yield, it is necessary to estimate the amount of soil loss from a given plot of land. The universal soil loss equation (USLE), developed by Wischmeier and Smith (1978) in the United States, has been the most widely used soil loss equation for over 30 years. Since then, the USLE has been revised and adapted to different regions of the world to reflect specific situations. Hurni (1988) has modified (calibrated) the universal soil loss equation to adapt to the Ethiopian Conditions.

In this study, the modified USLE equation is used to estimate the rate of soil loss from different land class categories in Anjeni Area, North Western Ethiopia. Comparison of the rate of soil loss calculated based on the USLE adapted to Ethiopia to the rate of soil loss from Anjeni soil conservation research station has also shown closer results. This justifies that USLE adapted to Ethiopia can safely be used to estimate the rate of soil loss. The modified universal soil loss equation (USLE) used to estimate soil loss based on topography, rainfall, soil type, land cover and land management practices is presented in Appendix -1.

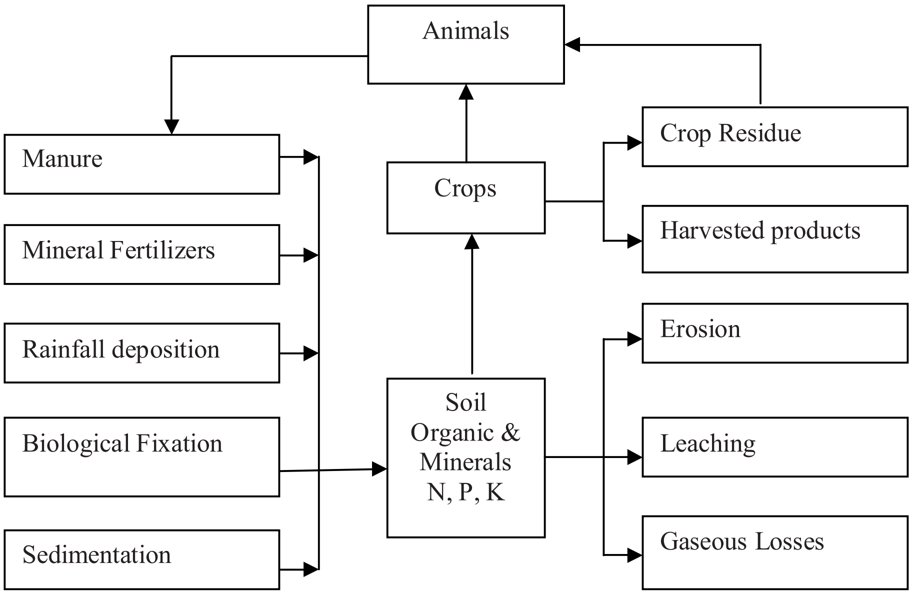
Soil conservation experiments were undertaken in Anjeni area using Soil and/or stone bund and *fanaya juu* on farmer's field from 1984 to 1993. Based on these experiments, it was found out that on average, Bund and *fanaya juu* reduced soil loss respectively by 63% and 81% as compared to the control plots or plots without soil and water conservation structures (SCRP, 200). Mostly, farmers use soil and stone bunds or a mixture of the two. Improved physical soil and water conservation technologies which have more or less similar effect on reducing soil erosion (soil/stone bund and *fanaya juu*) and one control (without soil conservation technology) are considered in the model. Soil conservation structures last more than one production season and the initial soil conservation structures deteriorate (depreciate) through time. Based on a discussion with farmers, soil conservation structures may last 2 to 4 years.

5.4.4.2 Soil Nutrient Balance: Nitrogen Inflows and Out Flows

Soil is a renewable natural resource that can supply soil nutrients and environmental services indefinitely because it has the capacity to regenerate through natural process of weathering and microbial decomposition of organic matter (LaFrance, 1992). Estimating the amount of soil loss due to soil erosion and the effect of improved soil and water conservation structures in reducing soil loss helps to understand their impact on soil nutrient balance. Studies on soil nutrient contents give emphasis on essential macro plant nutrients in the soil. Among these macro nutrients, Nitrogen in the form of ammonium (NH_4^+) or nitrate ($N0_3$-) is considered to be the most important macro-nutrient required by plants, hence limits crop yield (Hubbell, 1995).

Since one of the main objectives of this study is to evaluate the effects of different policy incentives and technology interventions on the quality of soil in Anjeni area, the Nutrient Monitoring (NUTMON) model developed to assess soil nutrient balance at different levels (Roy *et al*., 2003) is used. According to Roy *et al*. (2003), this approach has bridge a methodological gap in the assessment of soil nutrient balance by accounting for spatial variation of soils and climate and through improving the procedures for calculating nutrient flows and quantifying soil nutrient stocks. Figure 5.2 shows the framework of the NUTMON approach for analyzing soil nutrient balance in the soil and the interrelationship between major inflows and outflows of nitrogen in the soil.

Figure 5.2: Inflows and outflows of nitrogen nutrients in the soil



Source: Roy *et al*. (2003)

The major sources of nitrogen nutrient inflows include: the application of mineral as well as organic fertilizers, atmospheric nitrogen deposition because of rainfall, biological nitrogen fixations and nitrogen from sedimentation of flooded lands. The major mechanisms of nutrient outflows (nutrient removal), on the other hand, include: removal of nitrogen through the harvests of crops and crop residues, the washing away of soil nutrients from croplands due to soil erosion, leaching of soil nutrients and gaseous losses.

The procedure used to estimate the major nutrient inflows and outflows in order to calculate soil nitrogen balance based on NUMON approach is described in Table 5.10. Table 5.10 indicates that mineral fertilizers supply nitrogen in a form which is directly available for plant uptake.

Table 5.10: Procedures in NUMON approach to estimate soil nutrient balance

Nutrient flows	Formula used	Descriptions
Major Nutrient Inflows		
Mineral fertilizer	$0.18*DAP+0.46*Urea$	DAP and Urea are the most commonly used inorganic fertilizers in Ethiopia. They have respectively 18% and 46% nitrogen contents by weight. The quantity and composition of each fertilizer applied to different crops multiplied by the nitrogen content of fertilizers is considered.
Manure	$N_{manure}*Manure$	Nitrogen (N) from this source is not included due to lack of reliable data and due to the fact that farmers are increasingly dependent on manure for cooking fuel.
Rainfall deposition	$0.14*(RF)^{1/2}$	The average annual rainfall (RF) is used to calculate the amount of nitrogen from rainfall deposition
Nitrogen fixation	$2+(RF-1350)$ $*0.005+qsymb$	N-fixation occurs as a result of non-biological process (non-symbiotic) & biological (symbiotic) process. Only non-symbiotic process is considered & the average annual rainfall of Anjeni is used to calculate the amount of nitrogen
Sedimentation	300 mm/ha/year of water is used on irrigated lands; Limited information also indicated that 10 kg/ha of N could be used	Accounts the amount of nitrogen when the plot is flooded with water especially in irrigated lands and low lying lands. However, farmers in Anjeni area use rain fed agriculture and there are no irrigated lands. Moreover, hardly any information on the nutrient content of sediments could be traced. Therefore, nitrogen inflow from sedimentation is not considered.
Major Nutrient Outflows		
Harvested crop	$\sum\left(\frac{Area*N\,content*Yield}{Total\ Area}\right)$	Different crops withdraw different amount of soil nutrients from the soil. The average amount of nitrogen nutrient taken up by crops is considered
Crop residue	$\frac{\sum Area*N\,content*Yield}{Total\ Area}$ $*removal\ factor$	This accounts for the amount of soil nitrogen taken up through the residue of crops. It took in to account the estimated proportion of crop residue removed from the crop land after harvest.
Erosion	$\sum\left(\begin{array}{l}Eroded\ soil*Ncontent\\ *enrichment\ factor\end{array}\right)$	The NUMON model established an enrichment factor by assuming that part of soil nutrient lost on top soil is gained at the bottom
Leaching	$N\,soil(0.021*RF-3.9);$ $clay<35\%$	The amount of rainfall, the nutrient and clay content of soils influence the amount of nutrient that leach to underground and nutrient losses through gaseous vaporization. Nutrient outflows through this process is negligible and was not considered in the model
Gaseous losses	$N\,soil*(-9.4+0.13*clay$ $+0.01*RF)$	

Source: Adapted from Roy *et al*. (2003) and Tchale (2005)

Nitrogen fertilizer is assumed to be directly available for plant growth. Therefore, the efficiency of fertilizer is usually set at one (Tesfamicael, 2005). If organic fertilizers, such as crop residues and manure, are retained or applied on farm plots, nitrogen can be released as mineral nitrogen when they decompose in the soil. However, despite farmer's long tradition and higher preference for organic fertilizers, such as manure and crop residue to restore soil fertility in Anjeni area, the amount they apply on their croplands is very limited, mainly, due to the limited number of livestock they keep and the ever increasing use of manure for fuel due to the scarcity of fire wood.

Rainfall deposition occurs when rain carries gases and particles from the atmosphere to the earth's surface. Rainfall contributes atmospheric nitrogen through rain drops that reach the soil and can be available for plant growth (Aune, 1995). Soil erosion and uptake of soil nutrients from the soil by crop plants are considered to be the major nutrient outflows from the soil. Rainfall washes away soils along with soil nutrients and affects the balance or availability of soil nutrients for plant growth significantly. Other minor mechanisms of nutrient removal from the soil include leeching and gaseous losses. Nutrient inflows and out flows in Anjeni area on different land types under different land management practices are estimated based on NUMON approach developed by Roy *et al*. (2003). The specific formulation used to compute nitrogen balance in the soil based on the NUMON approach is specified in equation (5.57).

$$
\begin{aligned}
NB_{s,c,sc,f} &= Nrate_{(c,f)} * x_{s,c,sc,f} + \left[Nrain + Nfix_c \right] * A_{c,s,sc,f} \\
&\quad - NSE_s * se_{s,c,sc,f} - \left[Ncrop_c * y_{c,s,sc,f} * x_{s,c,sc,f} \right] \\
&\quad - \left[Rfactor_c * pcres_c * Nres_c * y_{c,s,sc,f} * x_{s,c,sc,f} * \right]
\end{aligned} \tag{5.57}
$$

Where, $NB_{s,c,sc,f}$ denotes the nitrogen balance on land type *s,* crop *c,* soil conservation status *sc* and fertilizer *f;* $Nrate_{(c,f)}$ is the rate of nitrogen applied from fertilizer *f* on crop *c* (kg/ha/year); $A_{s,c,sc,f}$ denotes area of land type s, under crop *c,* with soil conservation status sc and fertilizer rate f; $Nrain$ is the amount of nitrogen from rainfall deposition (kg/ha/ year); $Nfix_c$ is the rate of biological nitrogen fixation for crop c (kg/ha/year); NSE_s

is the coefficient that convert soil loss to nutrient loss for land type s; $se_{s,c,sc}$ is the amount of soil erosion from land type *s*, under crop *c* and soil conservation technology sc; $Ncrop_c$ is the nutrient composition of crop *c* (proportion by weight); $y_{c,s,sc,f}$ is the yield of crop type c on land type s with soil conservation status sc and fertilizer rate f; $Rfactor$ is a crop residue removal factor; $pcres_c$ is the pproportion of residue of crop *c* to its yield and $Nres_c$ denotes the nutrient composition of residue of crop *c* (proportion by weight).

5.4.5 Rainfall and Yield Variability

The dependency of agriculture on rainfall and seasonal and annual variability of rainfall have been the main causes of food insecurity and poverty in different regions of Ethiopia since 1970s. Yield variability can be explained, partly, by rainfall variability. The amount, pattern and frequency of rainfall influence crop yield. The commonly used indicator, the mean annual rainfall, as an index for analyzing the relationship between yield and rainfall may not clearly indicate the specific situation. The critical question would be, then, when and how often a place receives enough amount of rainfall for crop production to be carried out successfully.

Systematic and detail studies on the variability and trends of rainfall, specific to regions, zones or districts in Ethiopia are limited. A study by Bewket (2007), however, has shown that there are significant differences in rainfall amount, variability and trend in the highlands of Ethiopia. Rainfall amount is higher and its variability is lower in the western than in the eastern part of Amhara region. According to Bewket (2007), examination of trends in annual and seasonal rainfall, generally, shows absence of any systematic patterns of change across the Amhara region but significant correlations were observed between the amount of seasonal rainfall and crop production.

Discussions with farmers on timing and variation in the amount of rainfall in Anjeni area, in the north western part of Ethiopia indicate that there is yield variability associated with the rainfall variability. According to farmers, the most critical impact of rainfall variation or failure comes in May when plating begins and in September and October when most crops are at flowering and maturity stage. The amount of rainfall in May and September, are so critical for farmers and affect both planting and yield at the end of the production season. In the north western parts of the country, July and August have uniform and sufficient amounts of rainfall and the amount of rainfall and its variability is less of a constraint for crop production in these months.

The probability of crop production failure or reduction in crop yield in a particular year is mainly associated with the variability in the amount of rainfall in May and September. In cases where the levels of yield of different crops corresponding to the rainfall amount is available for some period of time, it is possible to compare the level of yield with rainfall amount and find out the probability that rainfall may fail in a given period of time.

In order to get some estimates of subjective probabilities about the state of rainfall related to crop yield variability in Anjeni area, sample households were asked and group discussions were conducted on the nature of rainfall, its pattern and effect on crop yield during the past 10 years (1998-2007) to elicit the conditional yield levels of different crops and the percent of yield deviation from the current yield level. Accordingly, there were 1 bad year, 7 medium and 2 good years during this period. This indicates that the probability of being bad year is 0.1(1 in 10 years), the probability of being medium year is 0.7 and the probability of being good year is 0.2. The probabilities of the three states of nature (good, medium, and bad) and the conditional crop yield levels for major crops under the three stats of nature are presented in table 5.11.

Table 5.11: Conditional yield level of major crops under different states of rainfall

	Yield under different States of rainfall (kg/ha)			Deviation from Medium	
	Good	Medium	Bad	Good	Bad
Probabilities	0.20	0.70	0.10	-	-
Teff	1563.55	1175.60 (449.65)	705.36	+33%	-40%
Barley	1734.63	1387.70 (370.22)	693.85	+25%	-50%
Wheat	2309.50	1847.6 0 (579.11)	923.80	+25%	-50%
Bean	1445.59	1010.9 0 (342.16)	707.63	+43%	-30%

Source: own survey (2007); numbers in the bracket are standard deviations

The yield levels under the medium state of nature are based on the 2007 yield levels collected from sample farm households. The yield levels under good and bad state of rainfall are calculated based on the percent of yield deviation from the current yield level under medium state of rainfall. Farmers have indicate that, since there are variations in planting dates for different crops and length of growing period, rainfall failure in may and September has slightly different impacts on the yield of the four major crops.

CHAPTER SIX

THE EFFECT OF POLICY INCENTIVES AND TECHNOLOGY ON SUSTAINABLE LAND MANAGEMENT AND HOUSEHOLD INCOME

6.1 Introduction

Before simulating policy and technology scenarios, it is necessary to understand how good the bioeconomic model is in terms of its ability to represent the real situation or observed behaviours and the extent to which it allows uncertain changes in parameter values so that the results of the model remain valid and meaningful.

Usually, there are two measures used to indicate whether a given model is good enough to represent observed behaviours. The first one is called robustness test. It measures the degree to which a given model can accurately describe a relevant part of reality. A model may be robust if it reproduces reality when the values of exogenous parameters are plugged in. The second one is called sensitivity analysis. It is used to evaluate the sensitivity of model outcomes to uncertain values of the parameters of the model. The sensitivity analysis compares model outcomes for variations in the model parameters. The less sensitive (more stable) a model is to changes in model parameters, the more useful and reliable it would be for further analysis.

The rest of this chapter is organized as follows: In section 6.2, the results of the base run results against which scenario analysis are compared are presented; the robustness of the model is checked in section 6.3 and sensitivity analysis for selected parameters is carried out in section 6.4. In section 6.5, the results of simulated model scenarios are presented and discussed. Finally, section 6.6 concludes the discussions and draws some policy implications.

6.2 Base Run of the Bioeconomic Model

The basis upon which scenario analysis are carried out in a mathematical programming model is the base run of the model. The outcome of the base run in this study is derived or estimated, mainly, from the primary data collected from Anjeni area in 2007/2008 agricultural production season. The base run is undertaken for two groups of small farm households in Anjeni area classified based on factor analysis technique. The two groups of households differ in resource endowment, mainly, in the area of land they possess, availability of oxen power, family labour endowment, availability of own cash for financing their farm activities. The criteria and details of farm household classification are given in section 2.3.1.1. Using some of these characteristics of farm households, the baseline results of the model are computed using the General Algebraic Modelling System (GAMS) software and presented in table 6.1.

The base line results for the two groups of farm households include: cropping activities, expected income and soil nutrient balance. The outcome of the optimal solution of the non-calibrated linear programming model revealed that the optimal solution consists of only *Teff* and Wheat production, excluding Barley and Horse Bean from the production plan. This necessitated calibration of the linear programming model with positive mathematical programming (PMP) technique to make the outcome more realistic compared to the observed cropping pattern.

Table 6.1: Base-run model results for two groups of farm households

	Household group	
Variables	Group-I	Group-II
Crop activities (ha)		
Teff	0.41	0.279
Barley	0.40	0.466
Wheat	0.18	0.274
Horse Bean	0.02	0.231
Income(ETB)	5,960.79	6,620.22
Soil nutrient (N) balance		
S1 (ton/ha/year)	-0.0460	-0.04704
S2 (ton/ha/year)	-0.1493	-0.15152
S3 (ton/ha/year)	-0.3188	-0.32152
S4 (ton/ha/year)	-0.6830	-0.66728

The crop production structure that consists of four major crops indicates that Barley and *Teff* occupy the major shares in both groups of households. However, there are differences between the two groups of households with respect to the proportion of crops grown, mainly Horse Bean and Wheat. The difference in optimal crop choice in the base run may be due to the difference in resource endowment, mainly land and working capital. The difference in optimal crop choice due to the difference in resource endowment also results in different income levels.

Second, the baseline result of the model indicates that both groups of households are mining the soil. The soil nutrient balances for both groups of households on all land class types are negative. The degree of soil nutrient depletion varies across the different land classes. However, the extent of soil nutrient depletion by the two groups of households is more or less similar.

6.3 Model Validation: Robustness Test

Model validation or test of robustness refers to evaluating the ability of a model to represent the real situations or observed behaviours. This involves comparison of model results with empirical evidences such as actual farm activities and resources. If model results are closer to the reality, then the model is considered to be a good model and can be used as a base for scenario analysis.

The degree to which a model can accurately describe a relevant part of reality can be applied to different time scales: to the short run and to the long run (Kruseman, 2000). A model may be robust in the short run if it reproduces reality when current values of exogenous parameters are used. A model is considered robust in the long run if the trend indicated by the model results coincides with the trend in historical evidence which depends on availability of consistent time series data. In this study, the short run robustness of the model is assessed by comparing and testing the outcomes of the base line model solutions to empirical evidence from survey data. To assess the short run robustness, the following statistically robustness test procedures are employed (Kleijnen, 1998 in Kruseman, 2000):

(6.1) $$(x^m - x^e) = \beta_0 + \beta_1 (x^m + x^e) + \gamma$$

Where, x^m denotes model result and x^e represents empirical evidence and γ is the error term. If the model is robust, the parameters β_0 and β_1 are expected to be zero (the null hypothesis). The null hypothesis that $\beta_0 = 0$ and $\beta = 0$ can be tested with the standard F-test. According to the Kleijnen procedure, a valid model indicates that there is a high degree of association between the model results and observed values and the correlation coefficient between the model results and observed values should be strong for the model to be efficient (Kruseman, 2000).

To get an indication of the validity of the model based on Kleijnen's statistically robust test, equation 6.1 is used as a criterion and the correlation coefficient is computed. Table 6.2 shows the empirical data and the corresponding model results from the base run and the robustness test results for the two groups of households. Based on the result of the regression in table 6.2 below, the F-statistics shows that the null hypothesis cannot be rejected at 95% confidence level indicating that the model is valid (robust) and the correlation coefficient between the model results and observed values is 0.79 (significant at 0.05 level).

Table 6.2: Regression results for testing the robustness of the model

Household Groups	Production Activities	Observed values	Model results
Group-I			
	Teff	0.24	0.410
	Barley	0.36	0.40
	Wheat	0.22	0.183
	Horse Bean	0.18	0.020
Group- II			
	Teff	0.30	0.279
	Barley	0.45	0.466
	Wheat	0.28	0.274
	Horse Bean	0.23	0.231
Test results	β_0	β_1	F-value (sig.)
Coefficients	-0.151	0.266	4.236 (0.085)
t-statistics (sig)	-1.951 (0.099)	2.058 (0.085)	

6.4 Sensitivity Analysis

A mathematical programming model is influenced by key parameter values and assumptions. Because of the need to reduce the unwanted consequences of misspecifications or uncertainties in parameter values, a counter factual analysis called sensitivity analysis is usually done in economic modelling. Sensitivity analysis tries to answer questions of the type 'what is the consequence of misspecification of some parameter values or change in the values of parameters due to uncertain conditions. To get some clue on the robustness of the model with respect to the specification of parameter values, a given parameter value is changed and new results of the model are compared to the reference results to analyse the effects of the value chosen on the model results.

The procedure used to analyze the sensitivity of the model starts by defining the upper and lower limits of the parameters. Model outputs are generated for changes in the parameters using a number of equidistance steps from the lower to the upper bound. The following statistical test procedure is used to determine the degree to which the model is sensitive to changes in the parameter values where a given parameter is regressed on the indicator variable (Krusman, 2000):

(6.2) $$y_i = \beta_0 + \beta_1 x + \gamma$$

Where y_i is the indicator variable for model sensitivity (model output) and x is the parameter tested for its influence on model outcomes. The model is insensitive to changes in the values of a parameter if β is equal to zero (the null hypothesis) and the adjusted R^2 is high. If β_1 is not equal to zero, the null hypothesis is rejected implying that the parameter has a well defined influence on model outcomes.

After determining whether the selected model parameters do have a well defined influence on the indicator variable (s), the next step is to know the degree to which the model is sensitive to changes in these parameter values. In order to know the degree to which a model is sensitive to changes in the values of a given model parameter, a quasi-elasticity measure, θ, that represents the percentage change in the indicator variable given a unit change in the model parameter value is shown by the following equation (Krusman, 2005):

(6.3) $$\theta = \beta_1 (\frac{x_0}{y_{i0}})$$

Where x_0 and y_{i0} denote, respectively, the values of the parameter and the indicator variable in the base run. Low values of adjusted R^2 imply that variations in parameter values influence the model results but in an unspecified manner (random variation) (Krusman 2000).

In this study, parts of the model parameters are based on econometric estimation and some parts of the model parameters, such as resource constraints and prices, are empirical data. This means that there are so many parameters included in the model. Undertaking sensitivity analysis over all model parameters is tedious. Therefore, only three parameters that are assumed to be very important are considered for testing the sensitivity of the model under changing assumptions.

The main model results that are taken into account as indicator variables are income and soil nutrient balance while the parameters tested for their influence on model outcomes are the price of *Teff* output, the probability of the state of nature (probability of low rainfall) and soil erosion coefficient. These parameters are chosen due to uncertainty in their values and their assumed potential impact on model outcome. The regression results for sensitivity analysis are presented in Table 6.3.

The results on table 6.3 indicate that the model is not sensitive to changes in erosion coefficient. However, the price of *Teff* output and the probability of the state of nature do influence the objective variable, income, for both household groups, as the coefficient of the two parameters are statistically significant and the corresponding R^2 is high. This is expected because the price of *Teff* output has more weight on the objective variable compared to the price of other crops and directly influences farm revenue while the cost of input is kept constant. The probability of low rainfall (bad year) also affected income by influencing crop yield. However, the degree of influences of these parameters is very low as indicated by the quasi-elasticity coefficient on the last column of table 6.3. This indicates that fairly large changes in the price of *teff* and in the probability of rainfall are needed to have any effect on the objective variable.

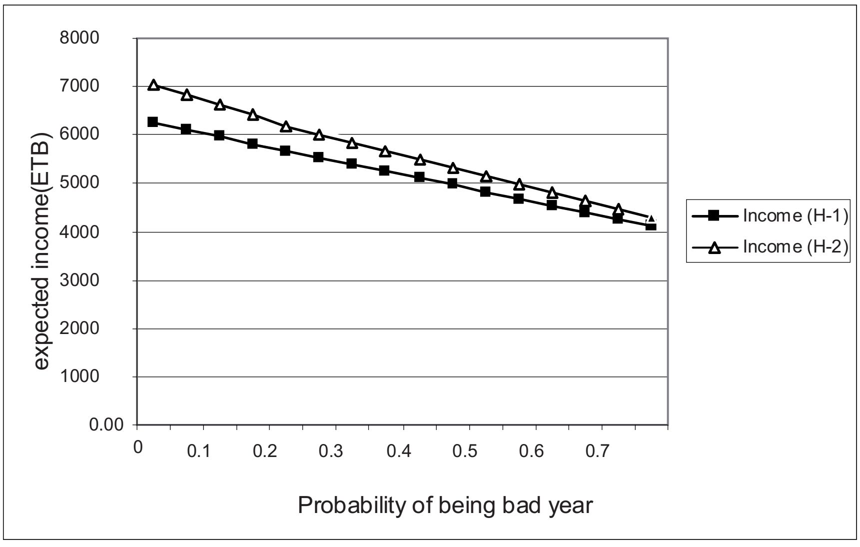
Table 6.3: Sensitivity analysis results for soil erosion coefficients and input costs

Parameters	Indicators	β_0	β_1	*t*-value(sig.)	R^2	θ
A) price of *Teff*						
Household-I	Income	7085.33	110.76*	2.80 (0.021)	0.47	0.149
Household-II	Income	5051.68	220.77**	7.82 (0.000)	0.87	0.267
B) Prob. of low rainfall						
Household-I	Income	6235.85	-2802.48**	-104.87(0.000)	0.999	-0.047
Household-II	Income	6952.56	-3616.30**	-83.422(0.000)	0.998	-0.055
C) Erosion coefficient	N_balance (ton/ha/yr)					
Household-I	S1	-0.1685	-0.5871	-1.912 (0.088)	0.289	31.767
	S2	-0.1703	-0.1818	-2.078 (0.067)	0.324	3.653
	S3	-0.1721	-0.0859	-2.089 (0.066)	0.327	0.808
	S4	-0.1731	-0.0399	-2.090 (0.066)	0.327	0.174
Household- II	S1	-0.0590	-0.2727	-2.078 (0.067)	0.324	17.392
	S2	-0.0631	-0.0868	-2.100 (0.065)	0.329	1.719
	S3	-0.0345	-0.0340	-1.442 (0.187)	0.206	0.317
	S4	-0.0619	-0.0198	-2.074 (0.068)	0.323	0.089

Note: ** and * indicate that coefficients are significant at 0.01 and 0.05 levels, respectively

Figure 6.1 also shows the impact of the probability of bad year (low amount of rainfall) on household income. The slope of the curves are not very steep indicating that changes in the probability of being bad year (low rain fall) don't drag the income of both household types to near zero level. However, at higher level of probability of low rainfall the two groups of households tend to perform similarly.

Figure 6.1: The probability of bad year (low rainfall) and household income



6.5. Simulation of Policy Incentives and technology Scenarios

The policy and technology scenarios considered in this study reflect the current and potential development interventions that may maintain or improve the productivity of crop lands and income of farm households. The bioeconomic simulation model was run for two representative groups of households classified based on factor analysis techniques as described in section 2.3.1.1. The two groups of households differ in terms of land size, labour endowment, working capital and oxen ownership that are important constraints in production and land management decisions. Different constraints and production activities are included in the model.

The two model results considered and compared among different scenarios are soil nutrient (nitrogen) balance on four different types of land, an indicator of soil quality, and household income, an indicator of household utility or welfare. The specific policy and technology scenarios used for simulation include: 1) the effect of improved soil and water conservation technology; 2) the effect of access to fertilizer credit; 3) the effect of improved crop variety; and 4) the combined effects of improved soil and water conservation technologies, access to fertilizer credit and improved crop variety.

6.5.1 The Shadow Prices of Resources

The comparison of shadow[1] prices of input constraints to their actual/observed prices can be used to evaluate the behaviour of optimization models (Hazell and Norton 1986). Depending on the basic information of the optimization problem, the shadow prices of resources are used to describe how the different policy and technology intervention scenarios considered in the model affect the production resources. The main production factors included in the model are land and labour.

[1] Negative values in GAMS output for constraint equations can be interpreted as the shadow prices of resources. The marginals in the GAMS model describe the changes of the objective variable 'on the margin' (i.e. small changes) due to changes in resource endowments or activity levels. For resources which are not fully utilized, the marginal values are zero, as these resources are not scarce. For activities which have positive levels, the marginal value is zero, as these activities are on a level which does not further increase the objective value. For activities which have zero levels, the marginal value is positive indicating the change in the gross margin of the activity level which would be necessary to let the activity enter the production programme, i.e. assume positive levels.

An examination of the shadow prices of resources in the base run for the two household groups indicate that land and availability of cash (own fund and/or credit), mainly for the purchase of fertilizer, are restricting crop production in Anjeni area. However, labour is not a limiting factor to agricultural production, even in the pick months of crop production and hired labour is zero in all months of the year. This indicates that labour is underutilized by the farmers due to relative scarcity of land. Moreover, farm household members can't fully utilize the idle labour, especially, during slack production seasons, as the availability of off-farm jobs is very limited. Given the low opportunity cost of labour, investments in improved soil and water conservation structures and tree planting on marginal and degraded lands seem very important to improve the productivity of land.

Land is a public property in Ethiopia and land transactions (buying and selling) including mortgaging is prohibited by law. Since 1991, land rental markets are legally permitted; however, the number of farm households who rent-out their land in Anjeni area has declined considerably. In 2001, for example, 8.1 % of farm households in Anjeni area rented-out part of their farm land and cultivated the remaining (Kassie and Babigumira, 2001) compared to 3.5% during our survey in 2007. As a result, land renting is not considered as an activity in the model. However, to have an estimate of the rental value of land for comparison with the shadow prices of land, the types of land contract arrangements practiced in Anjeni area are described in the next paragraph.

Based on discussion and interview with farmers, there are two types of land contracts in Anjeni area: share cropping and cost sharing. Share cropping is the most commonly used contract arrangement in Anjeni area. In this type of contract, the owner of the land doesn't share input costs but gets, mostly, between one-fourth (25%) and one-third (33.3%) of the crop output at the end of the production season, though this may vary depending on the fertility of the land.

In the second type of contract, both the owner of the land and the household who rent-in the land share the cost of inputs, mainly fertilizer and seed, and they share the output equally. In both types of contracts, the household who is renting-in the land has full responsibility to use his own labour and animal traction (oxen power) for cultivation.

Therefore, the first type of contract, which is based on the value of shared (25%) crop output, is used as an indicator of rental value of land for comparison with the shadow value of land.

Table 6.4 shows the changes in the shadow values of four types of land under different policy and technology intervention scenarios. The tables indicate that the shadow values of land type one (S1) and land type two (S2) are generally higher than the shadow values of land type three (S3) and land type four (S4) because of higher crop yields and lower cost of labour for the construction of improved soil and water conservation measures on these, relatively, fertile and gentle slope lands. The decline in crop yields on steeper slopes reduces the values of land. Land type three (S3) and land type four (S4) have steeper slopes, hence requires more labour for the construction of improved soil and water conservation measures.

Unexpectedly, the roughly estimated rental values of different land classes are generally higher than the base line scenarios (scenario-1) for both household groups. Compared to the base-line scenario, the introduction of improved soil and water conservation technology (scenario-2) increased the value of land type one (S1) for household group-II, but reduced its value on lands that have steeper slopes. For household group-I, the shadow value of land is zero, due to the fact that very small amount of working capital restricted crop production compared to availability of land.

The introduction of credit for the purchase of fertilizer (scenario-3) increased the value of land for household group-I considerably as compared to the base line scenario. Access to credit enabled these farm households to purchase additional fertilizer. However, limited availability of land starts binding cropping production. Compared to the base run, household group-II did not apply more fertilizer as a result; the introduction of credit didn’t improve the value of land for household group-II. This implies the importance of targeted intervention in providing access to credit for farm households.

The introduction of improved wheat variety alone (scenario-4), without credit, increased the value of land only for household group-II. Since working capital remains the significant limiting factor for household group-I, the introduction of improved crop variety without credit didn't improve the value of land. The combined scenario (scenario-5) improved the shadow value of land considerably for both household groups.

Table 6.4: The shadow prices of land under different scenarios

Household groups	Land type	Shadow Prices of land (ETB)					Observed[1] (Estimated) values (ETB)
		Base-Run (1)	ISWCT (2)	Fertilizer Credit (3)	HYV (4)	Combined Scenarios (5)	
Group-I	S1	-	-	714.61	-	865.98	1787.00
	S2	-	-	673.29	-	1237.38	1780.73
	S3	-	-	714.75	-	1256.92	1624.54
	S4	-	-	672.36	-	1242.27	1618.84
Group-II	S1	335.68	432.60	335.68	516.59	432.60	1787.00
	S2	277.65	253.16	277.65	458.28	437.81	1780.73
	S3	139.07	112.79	139.07	316.21	294.04	1624.54
	S4	31.59	6.28	31.59	212.42	191.13	1618.84

Note: ISWCT and HYV denote improved soil and water conservation technology and high yielding variety.

6.5.2 The Effect of Improved Soil and Water Conservation Technologies (ISWCT)

Improved soil and water conservation technologies are of primary importance to reducing the threatening effect of soil erosion and maintain the productivity of agricultural lands. Land degradation can be slowed down by a wide range of options, including physical soil conservation measures such as soil bund, stone bund, *fanaya juu.* Such types of structural conservation measures are more desirable in areas with high intensity rainfall areas such as Anjeni. The benefits of constructing improved soil

[1] Unexpectedly, the roughly estimated rental values of land based on the value of shared crop output are generally higher than the shadow value of land in the base line scenario. In a situation where there is no market price for land, a real justification can't be found for such type of rough estimates. These estimated values are not, therefore, dependable and one may even decide not to compare the observed value of land with the shadow vale of land in this particular situation. However, trying to have such estimates for comparison always provides a picture of complete frame work of comparison in analysing the resource use pattern and the behaviour of farm households

and water conservation technologies may last more than one production season. As a result, the decision to construct them may be treated as an investment on land over some period of time and the shadow value (user cost) of soil and water conservation structures and appropriate discount rates can be used to describe the optimal soil conservation decision if consistent time series data are available.

Inter-temporal evaluation of costs and benefits of improved soil and water conservation technologies can provide valuable information about farmers' own incentives to invest in such methods purely on profitability grounds. Cost benefit analysis of improved soil and water conservation measures in the highlands of Ethiopia have indicated that the level of soil erosion achieved under conserving practice, the labour costs of investment and the farmers' subjective rate of discount determine the profitability of switching onto the new technology (Shiferaw and Holden, 1998). However, profitability or economic factor alone can not insure adoption of improved soil and water conservation technologies. As discussed in chapter 7, adoption is also influenced by a set of non-economic variables.

In the absence of consistent and up-to-date time series data, static optimization model results can be used to evaluate the impact of improved soil and water conservation technologies on soil erosion, nutrient balance and income level of small farm households in the short run as they have also immediate effects on soil erosion and crop yield. Obviously, if soil conservation investment has a positive impact in the short run, it will have a positive impact in the long run due to the fact that the cost of investment is incurred in the first year and the benefits flows over longer periods.

In this section the effects of improved soil and water conservation technologies, soil/stone bund are assessed with respect to their impact on soil nutrient balance and income of small farm households in Anjeni area. The effects of adopting improved soil and water conservation technologies on soil erosion and soil nutrient balance under four different land classes for the two groups of farm household are presented in table 6.5.

The short term income effects of improved soil and water conservation technologies for both household groups on all land classes is positive but very small to justify its adoption by small farm households. The positive income effect of improved soil and water conservation measures, though very small, can be explained by the fact that the moisture retention (water conservation) effect of soil and water conservation measures on yield is higher than their effect on yield reduction due to area reduction. Especially, physical soil and water conservation measures take some land out of production and may some times have negative effect on crop yield.

Table 6.5: Impact of conservation measure on household income and soil quality

Parameter	Soil Conservation		Impact
	without	with	(% change)
Household Group-I			
Income (ETB)	5,960.790	5,973.230	0.209
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0460	-0.0135	-70.652
S2 (ton/ha/year)	-0.1493	-0.0444	-70.261
S3 (ton/ha/year)	-0.3188	-0.1121	-64.837
S4 (ton/ha/year)	-0.6883	-0.2029	-70.522
Soil Erosion			
S1 (ton/ha/year)	36.557	10.558	-71.119
S2 (ton/ha/year)	59.594	17.590	-70.484
S3 (ton/ha/year)	84.929	29.787	-64.927
S4 (ton/ha/year)	137.597	40.499	-70.567
Household Group-II			
Income (ETB)	6,620.220	6,699.140	1.192
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0470	-0.0197	-58.121
S2 (ton/ha/year)	-0.1515	-0.0534	-64.757
S3 (ton/ha/year)	-0.3215	-0.1330	-58.634
S4 (ton/ha/year)	-0.6673	-0.2340	-64.932
Soil Erosion			
S1 (ton/ha/year)	37.334	12.286	-67.092
S2 (ton/ha/year)	60.463	16.939	-71.985
S3 (ton/ha/year)	85.636	28.278	-66.979
S4 (ton/ha/year)	133.390	37.372	-71.983

Physical soil and water conservation measures have direct impact in mitigating soil erosion and thus affect soil nutrient balance and crop yield. As described in section 5.4.3.1, four different types of land categories were classified based on soil colour and slope of the land and soil nitrogen balance is used as an indicator of soil quality. As indicated on table 6.5, the average soil loss without improved soil and water conservation measures ranges from 36.557 tons/ha/year to 137.597 tons/ha/year for household group-I and from 37.334 tons/ha/year to 133.39 tons/ha/year for household group-II.

Obviously, the amount of soil loss is much higher on lands without soil conservation measures compared to the case with improved soil and water conservation measures. For both household groups and on all land types, improved soil and water conservation measures could reduce soil erosion by more than 58%. The average rate of soil loss declines substantially as we move from land type four (S4) to land type one (S1). The amount of soil loss is relatively higher on land type three (S3) and land type four (S4) as compared to land type one (S1) and land type two (S2), mainly, due to the effect of topography (slope of the land).

6.5.3 The Effect of Access to Fertilizer Credit

Sufficient and timely access to credit for small farm households is crucial to realize the full potential of subsistence agricultural production and rural development. However, shortage of financial resources or lack of credit is generally considered to be one of the bottle necks that small farm households in Ethiopia are facing today. Banks in Ethiopia do not lend to small farmers. This is because of lack of collateral, high transaction costs associated with credit administration, lack of education and low level of managerial skill by farmers which make credit lending by banks very risky, costly and difficult (Admassie, 2003).

Currently, there is a strong believe that Micro Finance Institutions (MFIs) are good instruments to fill the gap that conventional banks have limitations in reaching the poor farm households with banking services and to empower them economically and socially (Yelewemwessen, 2008). As a result, the government of Ethiopia and non governmental organizations (NGOs) have considered and founded different Micro Finance Institutions (MFIs) to support pro-poor development programs and strategies during the past 10 years. According to Yelewemwessen (2008), by December 2007, there were about 27 licensed Micro Finance Institutions in Ethiopia. However, they were able to meet only less than 20% of the demand for micro-finance services both in rural and urban areas due to institutional capacity constraints and lack of loan capital.

In Anjeni area, there is one Micro Finance Institute called Amhara Credit and saving Institute (ACSI) which is founded and operate in Amhara region. Amhara Credit and saving Institute (ACSI) targets, relatively, poor households and it has outreached only 25%-30% of the potential demand for microfinance by December 2007 (Yelewemwessen, 2008). Though promising, most of the credit demand in the region still remains unmet indicating that further efforts should be exerted in order to improve the livelihood of subsistence farmers. It has been noted that efforts to improve food security with only little use of external inputs were not able to make a wide impact on the livelihood of farm households. Improved use of agricultural input such as fertilizer and high yielding variety is, therefore, considered as a necessary prerequisite to poverty alleviation and circumventing land degradation in Ethiopia. This implies that access to credit, among other things, help to insure the wide use of these inputs.

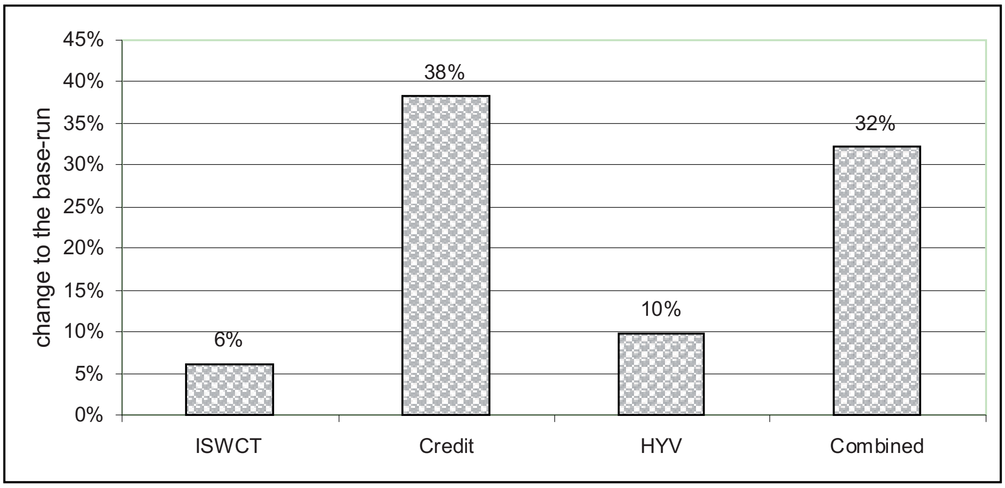
During our survey, farm households in Anjeni area reported that lack of credit for the purchase of fertilizer, improved seeds and other production inputs is one of the major constraints they face. The Government of Ethiopia also considers fertilizer as a strategic input to ensure the national food security. In this section, the impact of access to short term fertilizer credit towards improving the income of small farm households and its indirect impact on improving the quality of soil is analysed. The effect of credit for fertilizer on household income and soil nutrient balance under different land classes for the two groups of households is presented in table 6.6.

The results indicate that limited access to credit has a positive impact on income and soil nutrient balance only for household group-I. The apparent effect of credit on the income of household group-I is primarily due to its effect in financing the purchase of inputs that have direct impact on crop yield. As shown on figure 6.2, the use of fertilizer by household group-I has increased by about 38% as a result of limited access to fertilizer credit. Credit availability addresses the cash constraints of household group-I who lack the necessary working capital (cash) to finance the purchase of fertilizer and other important production inputs. However, the impact of credit access for fertilizer and other input does have little/no effect on soil nutrient balance for group-I.

Table 6.6: Impact of fertilizer credit on household income and soil quality

Parameter	Limited access to Fertilizer Credit		Impact (% change)
	without	with	
Household Group-I			
Income (ETB)	5,960.79	6,320.55	6.04
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0460	-0.0459	-0.22
S2 (ton/ha/year)	-0.1493	-0.1462	-2.08
S3 (ton/ha/year)	-0.3188	-0.3153	-1.10
S4 (ton/ha/year)	-0.6883	-0.6709	-2.53
Soil Erosion			
S1 (ton/ha/year)	36.557	36.332	-0.62
S2 (ton/ha/year)	59.594	58.294	-2.18
S3 (ton/ha/year)	84.929	83.98	-1.12
S4 (ton/ha/year)	137.597	134.101	-2.54
Household Group-II			
Income (ETB)	6,620.220	6,620.220	-
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0470	-0.04704	0.01
S2 (ton/ha/year)	-0.1515	-0.15152	0.01
S3 (ton/ha/year)	-0.3215	-0.32152	0.01
S4 (ton/ha/year)	-0.6673	-0.66738	-
Soil Erosion		0	
S1 (ton/ha/year)	37.334	37.3336	-
S2 (ton/ha/year)	60.463	60.4632	-
S3 (ton/ha/year)	85.636	85.6360	-
S4 (ton/ha/year)	133.390	133.390	-

Figure 6.2: Change in the use of fertilizer due to limited credit access



6.5.4 The Effect of High Yielding Crop Variety (HYV)

Crop production system in the highlands of Ethiopia relies heavily on traditional agricultural technologies and characterized by limited use of external yield increasing inputs such as improved crop variety and soil fertilizer for major crops. Despite the importance of improved seed in improving the livelihoods of small-scale farmers, its access is still constrained by inefficient production, marketing and distribution systems.

The Ethiopian seed industry is currently at the lowest stage of development. Improved varieties are developed by the national agricultural research system and development programs or introduced from outside (Hundie *et al*, 2000). Participation of Private companies in the production, marketing and distribution of crop seeds is very limited. As a result, the average yield of major crops in Ethiopia is lower than the average yield in other locations. For example, the mean Wheat yield in Ethiopia is 24% below the mean yield for Africa and 48% below the global mean yield (Hundie *et al*, 2000). This is attributed mainly to the low level of use of high yielding varieties and improved production technologies. Thus, Intensification of production using high levels of external inputs, such as improved seed and soil fertilizer, can help improve food security and income of subsistence farm households.

Discussion with farmers and agricultural development agents in Anjeni area showed that the district office of agriculture and rural development is responsible for buying and distributing improved crop seeds, mainly Wheat, to farmers at cost and they mentioned that the demand for seed has never been met due to the limited capacity to buy higher quantities and limited access to different crop varieties. Currently, the district department of agriculture and rural development in Anjeni area distributed improved Wheat seed variety at cost to some farmers. Improved Wheat seed is included in the model to evaluate its impact on the income of farm households and soil nutrient balance. The simulation model result of the effect of improved Wheat variety is presented in table 6.7.

The result shows that there are modest increases in income of the two household groups as a result of the introduction of improved Wheat variety. The income effect of improved Wheat seed is, a little bit higher for household group-II than for group-I, may be, due to the capacity of household group-II (relatively better endowed groups) to use more fertilizer along with improved variety. Improved seed increases the income of household group-I and households group-II, respectively, by 3.56% and 6.51%.

Table 6.7: Impact of improved Wheat seed on household income and soil nutrient

Parameter	Wheat Seed		Impact (% change)
	Local variety	High yielding variety (HYV)	
Household Group-I			
Income (ETB)	5,960.790	6,172.810	3.560
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0460	-0.0459	-0.220
S2 (ton/ha/year)	-0.1493	-0.1469	-1.610
S3 (ton/ha/year)	-0.3188	-0.3181	-0.220
S4 (ton/ha/year)	-0.6883	-0.6755	-1.860
Soil Erosion			
S1 (ton/ha/year)	36.557	36.550	-0.020
S2 (ton/ha/year)	59.594	58.567	-1.720
S3 (ton/ha/year)	84.929	84.698	-0.270
S4 (ton/ha/year)	137.597	135.018	-1.870
Household Group-II			
Income (ETB)	6,620.220	7,051.466	6.510
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0470	-0.0470	-0.170
S2 (ton/ha/year)	-0.1515	-0.1514	-0.106
S3 (ton/ha/year)	-0.3215	-0.3210	-0.149
S4 (ton/ha/year)	-0.6673	-0.6662	-0.168
Soil Erosion			
S1 (ton/ha/year)	37.334	37.271	-0.167
S2 (ton/ha/year)	60.463	60.357	-0.176
S3 (ton/ha/year)	85.636	85.495	-0.164
S4 (ton/ha/year)	133.390	133.156	-0.176

However, though very small, improved Wheat seed variety has negative effect on soil nutrient balance. This can be explained by the fact that soil nutrient uptake by crop plants depend on the crop biomass. The NUTMON model, described in section 5.4.4.2, explicitly considered the effect of biomass (grain and residue) on soil nutrient uptake. Thus, improved Wheat variety yields higher biomass and extracts, relatively, more soil nutrients from the soil than the local Wheat variety.

6.5.5 The Combined Effects of Improved Soil and Water Conservation Technologies, Access to Fertilizer Credit and Improved Crop Variety

Analysis of the model results above for selected individual policy and technology interventions indicate that there are some possibilities for improving household income and reducing degradation of soil quality as compared to the case without any intervention. Table 6.8 presents the model results for the combined effect of improved soil and water conservation technologies, access to fertilizer credit and improved crop variety on household income and soil quality. The combined effect of improved soil and water conservation measures, access to fertilizer credit and high yielding crop variety appear to have the highest impact on income and land degradation as compared to individual policy incentives and technology interventions scenarios as they address, simultaneously, several constraints of small farm households.

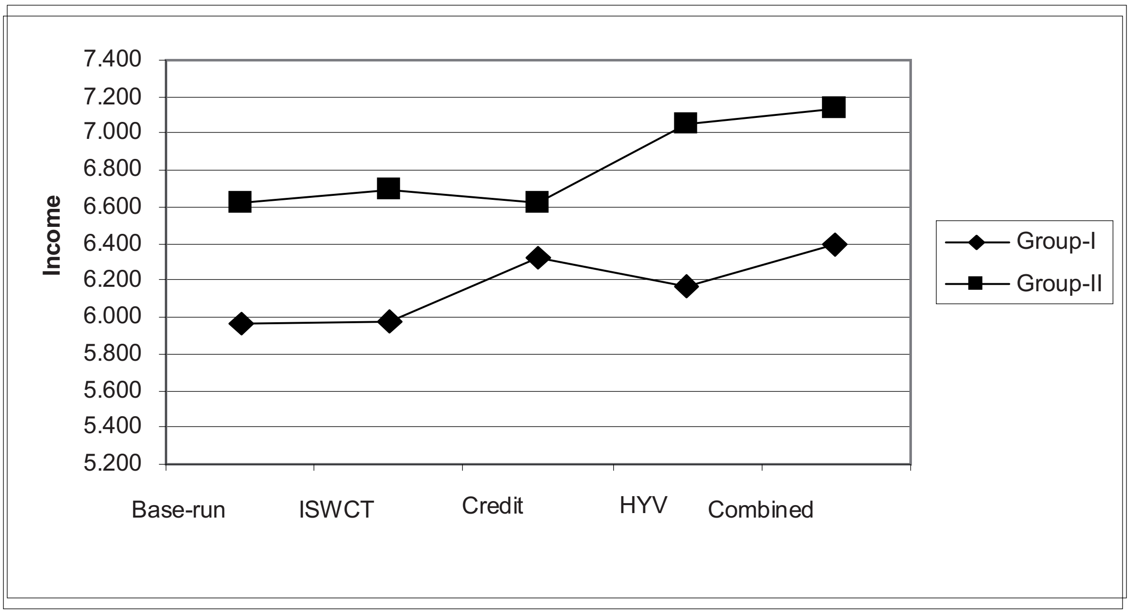
Table 6.8: The combined effect of policy incentives and technology interventions

Parameter	Base result	Combined Policy and technology scenarios	Impact (% change)
Household Group-I			
Income (ETB)	5,960.790	6,393.970	7.270
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0460	-0.0158	-65.650
S2 (ton/ha/year)	-0.1493	-0.0417	-72.070
S3 (ton/ha/year)	-0.3188	-0.1053	-66.970
S4 (ton/ha/year)	-0.6883	-0.1899	-72.410
Soil Erosion			
S1 (ton/ha/year)	36.557	12.218	-66.580
S2 (ton/ha/year)	59.594	16.476	-72.350
S3 (ton/ha/year)	84.929	27.953	-67.090
S4 (ton/ha/year)	137.597	37.898	-72.460
Household Group-II			
Income (ETB)	6,620.220	7,138.710	7.830
Soil Nutrient (N) balance			
S1 (ton/ha/year)	-0.0470	-0.0158	-66.327
S2 (ton/ha/year)	-0.1515	-0.0427	-71.806
S3 (ton/ha/year)	-0.3215	-0.1062	-66.957
S4 (ton/ha/year)	-0.6673	-0.1869	-71.994
Soil Erosion			
S1 (ton/ha/year)	37.334	12.326	-66.985
S2 (ton/ha/year)	60.463	16.908	-72.036
S3 (ton/ha/year)	85.636	28.230	-67.035
S4 (ton/ha/year)	133.390	37.304	-72.034

This scenario increases the income levels by more than 7% for both household groups and reduces nutrient loss by more than 66% for both household groups on all land classes. However, these policy incentives and technology interventions couldn't, simultaneously, increase income and soil nutrient balance.

The graphical representation of the effect of policy incentive and technology intervention scenarios on the income and soil nutrient balance of small farm households are also shown on figure 6.3, 6.4 and 6.5 below. Figure 6.3 shows that the impact of improved soil and water conservation technology on income of households is positive but negligible. The absence of short term benefit (return) from the construction of improved soil and water conservation measures imply the difficulty in promotion of the use of improved soil and water conservation measures by small farm households whose primary objective is family sustenance and daily survival of livelihoods in contrast to the long term benefit from soil and water conservation investment.

Figure 6.3: The effect of different scenarios on the income of households



However, the impact of improved soil and water conservation measures towards reducing land degradation is considerably high for both household groups as shown on figure 6.4 and 6.5. The two household groups differ in their response towards limited access to fertilizer credit as shown on figure 6.5. Access to fertilizer credit has a positive effect on the income of only household group-I by insuring the financing of the purchase of fertilizer and other production inputs.

Figure 6.4: Soil nutrient balance under different scenarios for household group-I

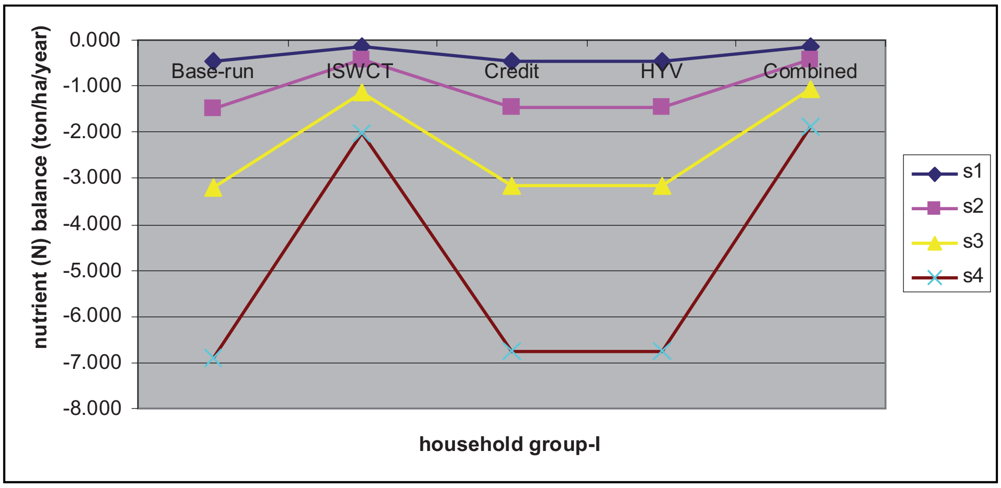
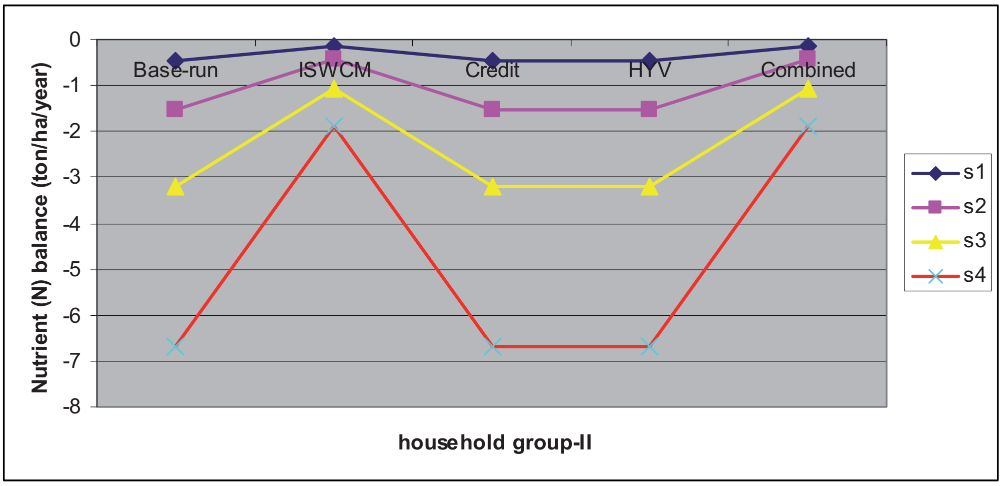


Figure 6.5: Soil nutrient balance under different scenarios for household group-II



While credit access enabled household group-I to use fertilizer and increase their income, household group-II, who have relatively better working capital, are less responsive to fertilizer credit. This implies the importance of targeted intervention in providing credit access in the area. Compared to group-II, the degree to which the response of the income of group-I to improved Wheat variety in the absence of credit is modest. However, improved Wheat variety, though negligible, has negative effect on soil nutrient balance due to the fact that improved Wheat variety yields higher biomass and extracts, relatively, more nutrients from the soil than the local Wheat variety. The modest impact of improved Wheat variety on income and the negative impact on soil nutrient balance suggest that improved crop varieties may not respond well without other technological packages such as fertilizer and soil conservation measures.

Figure 6.3, 6.4 and 6.5 show that the combined effect of improved soil and water conservation measures, access to fertilizer credit and the use of high yielding crop variety appear to have the highest impact on income and soil nutrient balance for both household groups. Figure 6.4 and figure 6.5 also show that the introduction of improved soil and water conservation measures has reduced land degradation significantly compared to the base line scenario for both household groups.

6.6 Conclusions and Policy Implications

The results of the bioeconomic-model, in general, indicate that the income of farm households can be improved and the rate of land degradation can be reduced via policy incentives and technology interventions. The introduction of improved soil and water conservation technologies could reduce land degradation significantly (by more than 58%) compared to the case without conservation. However, the use of physical soil and water conservation measures alone can’t sustain crop yield as soil erosion can’t be completely mitigated (only slowed down), suggesting that an integrated soil conservation approach, including biological and other soil conservation measures, should be adopted if farmers are to improve or sustain land quality and crop yield.

The results also indicated that the short term return from the construction of improved soil and water conservation measures is negligible. However, the main concern or motivation of most smallholder farmers in the Highlands of Ethiopia is the short term family sustenance and daily survival of livelihoods implying that government institutions and other non governmental organizations involved in the design and implementation of land conservation measures should have a mechanism by which they can provide incentives to farmers to motivate them construct improved soil and water conservation technologies.

The result also indicated that access to fertilizer credit has a positive effect on the income of only household group-I by insuring the use of fertilizer and other production inputs. This implies the importance of targeted intervention in providing credit access. The modest impact of improved Wheat variety on income and the negative impact on soil nutrient balance suggest that improved crop varieties may perform better along with technological packages such as fertilizer and soil conservation measures. Therefore, it is important to link provision of credit for fertilizer to the use of improved seed, as this improve both household income and soil quality.

The combined effect of improved soil and water conservation measures, access to fertilizer credit and the use of high yielding crop variety appear to have the highest impact on the income and quality of farmers' land as compared to other intervention scenarios. However, there are no win-win situations in all scenarios, i.e., policy incentives and technology interventions couldn't, simultaneously, increase both income and soil nutrient balance.

The model results also indicate that land is the most binding factor of production while the opportunity cost of labour is very low in Anjeni area. In addition, the agricultural potential is considered to be low while the density of the population is high, adoption of more input-intensive cereal production is still very limited due to moisture stress, shallow depth of the soil and absence of irrigation investments. Given the low opportunity cost of labour and the scarcity of land, activities that require little/no amount of land, such as Tree-planting activities on degraded lands and beekeeping activities, can provide opportunities to improve the income and welfare of small farm households to offset the pressure on land from growing population. The low opportunity cost of labour also implies that farmers can take advantage of soil and water conservation investments by increasing targeted use of fertilizer and high yielding crop varieties to improve land productivity if they are given incentives for conservation.

However, despite the opportunities for improvement in the productivity of land and other productive resources in the agriculture sector in Anjeni area, these strategies seem unlikely solve the long-term poverty problem facing farm households. This implies that non-farm sector development and employment opportunities seem to have great potential in the medium and long term to improve the livelihood of farm households as the area has relatively better access to main road and /or market and given the fact that there is high population density and land scarcity. In the long term, such balanced development of both the farm and non-farm sectors would be the key to achieving more sustainable use of land, economic growth and elimination of poverty.

CHAPTER SEVEN

THE USE OF IMPROVED SOIL AND WATER CONSERVATION TECHNOLOGIES

7.1 Introduction

Improving food security, alleviating poverty and ensuring sustainable use of agricultural lands remain to be the major challenges for smallholder farmers, government and other stake-holders in Ethiopia. Investments in soil and water conservation measures and the use of soil fertility management inputs have always been important factors in increasing the productivity and sustainability of agricultural lands.

The ministry of agriculture and rural development in Ethiopia has been promoting different kinds of agricultural technologies including improved soil and water conservation technologies and soil fertilizers since the early 1980s. Improved soil and water conservation technologies were introduced and promoted in the highlands of Ethiopia, including Anjeni area, to reduce soil erosion and improve or maintain agricultural productivity since the mid 1980s. However, evaluation of agricultural development programs generally shows that these technological interventions were important but insufficient and the level of impact was very low due to economic, policy and institutional constraints.

Like most highlands in the North Western Ethiopia, Anjeni area is characterized by highly dissected and steep terrain with very intensive rainfall, especially, in the months of July and August which makes it highly vulnerable to soil erosion. In order to curb the problem of soil erosion, different improved soil and water conservation measures, such as soil bund, stone bund and *fanaya juu*, were introduced with the help of SCRP since 1984 and then continually promoted both by the SCRP and the district's Office of Agriculture and Rural Development.

Despite the seriousness of soil erosion problem in the area and the high expected benefit from curbing soil erosion, the use of improved soil and water conservation technologies has remained limited in Anjeni area. This raises the question 'why farmers appear to be sluggish to use improved soil and water conservation technologies and why the adoption of soil and water conservation technologies has remained limited or sub-optimal despite the fact that different studies indicated high expected benefit from using improved soil and water conservation technologies.

In order to analyze this problem, data were collected from a survey of 196 sample farm households using semi-structured questionnaire, field measurement, group discussion and from key informants in 2007 to assess the factors that influence farm households towards using improved soil and water conservation technologies in Anjeni area, North Western Ethiopia, to complement the results from the bioeconomic model developed for Anjeni area to evaluate the impact of policies incentives and technology on sustainable land management and household income.

The rest of this chapter is organized as follows: section 7.2 presents the theoretical frameworks. The empirical model is specified in section 7.3 and the data and variables used in the model are described in section 7.4. The results are discussed in section 7.5 and, finally, section 7.6 concludes and draws policy implications.

7.2 Theoretical Framework

Soil erosion is a gradual process, which leads to removal of soil nutrients and declining soil depth (Favis, 2005). Soil erosion has both on-site and off-site effects. The decline in productivity occurring on the spot where degradation occurs is referred to as an on-site effect (Shiferaw and Holden, 1998). The on-site effect of soil erosion is the reduction in soil quality which results from the loss of the nutrient-rich upper layers of the soil, and the reduced water-holding capacity of eroded soils.

Soil erosion may also impose negative externalities in areas away from the point of degradation. This is called the off-site effect of soil erosion. Such off-site effects include deposition of infertile sediment on productive land in lower-lying areas, increased flooding downstream, pollution of water systems, siltation of lakes and dams, deposition of sediment in sewage canals (Shiferaw and Holden, 1998).

When off-site impacts of soil erosion are substantial, private investments in soil and water conservation may be sub-optimal from society's perspective. However, when private farmers choose to invest in soil and water conservation measures, they ignore the off-site effects of soil erosion and evaluate and decide based on on-site effects of soil erosion. Since land use decisions are ultimately made by farmers themselves in light of their own objectives, production possibilities and constraints under existing conditions, analyses based on private farmers' perspectives should only include perceived net benefit or utility that actually accrues to the private farmers making the decision to understand the incentives that affect adoption of improved soil and water conservation technologies (Shiferaw and Holden, 1998).

The decision to adopt a new technology by smallholder farmers could be considered under the general framework of utility or profit maximization (Rahm and Huffman, 1984). It is assumed that farmers use a given technology only when the perceived utility or net benefit from using the technology is significantly higher than would be the case without the technology. Given farm resources, including labour and income constraints, farm households maximize their utility from consumption of goods and leisure, given household and farm specific characteristics.

Construction of improved soil and water conservation technologies reduce soil erosion and improve or maintain agricultural productivity and farm income. On the other hand, construction of improved soil and water conservation measures require extra family labour and reduces leisure time available for farm households, especially when there is no well developed labour market where labour can be hired for construction of soil and water conservation measures. Thus, construction of improved soil and water conservation has two effects on farmers' utility: it reduces leisure time which affects their utility negatively and increases production and income which has a positive effect on their utility. Therefore, the observed adoption choice depends on farmers' comparison of perceived net returns from adopting and non-adopting an improved soil and water conservation technology.

Assuming that farmers respond to their circumstances in a consistent and rational utility maximizing way, they adopt improved soil and water conservation technology when the anticipated utility from adopting the technology exceeds that of non adoption. Let's define the use of an improved soil and water conservation technology, j where $j=1$ if a farmer uses the technology and $j=0$ if he is not using the technology. The non-observable underlying utility function that orders the preference of the i^{th} farmer to these two alternatives is given by $u(x_{ji})$. Where, x is a vector of farm and farmer specific variables as well as other attributes that influence the perceived desirability of the technology. Although the utility function is not directly observed, the actions of farmers are observed through the choice they make.

The relationship between the utility (u_{ji}) for a particular farmer (i) that can be derived from adopting improved soil and water conservation technology (j) is postulated to be a function of explanatory variables (x_i) that influence the perceived desirability of the technology plus a disturbance term γ_j, with zero mean and constant variance.

(7.1) $$u_{ji} = \beta_j x_i + \gamma_j\,;\; j = 0,1;\; i = 1,2,...,n$$

If we define a qualitative variable (D_i) which indexes the adoption decision of improved soil and water conservation technology, then we can express the relationship as follows:

(7.2) $$D_i = \begin{cases} 1 \;\; if\; u_{0i} < u_{1i}, & adopt \\ 0 \;\; if\; u_{0i} > u_{1i}, & don't\, adopt \end{cases}$$

The probability that a household will adopt improved soil and water conservation measures $(D_i = 1)$ could then be expressed as a function of explanatory variables:

(7.3) $$\begin{aligned} pr(D_i = 1) &= pr(u_{1i} > u_{0i}) \\ &= pr\left[\beta_1 X_i + \gamma_{1i} > \beta_0 X_i + \gamma_{0i}\right] \\ &= pr\left[(\beta_1 - \beta_0) X_i > (\gamma_{0i} - \gamma_{1i})\right] \\ &= pr\left[\beta' X_i > \gamma_i'\right] \\ &= F(\beta' X_i) \end{aligned}$$

Where $pr(.)$ is a probability function, $\gamma_i' = \gamma_{0i} - \gamma_{1i}$ is a random disturbance term, $\beta' = \beta_1 - \beta_0$ is a transposed vector of coefficients and $F(\beta' X_i)$ is the cumulative distribution function of the disturbance term γ_i' evaluated at $\beta' X_i$. The exact distribution of $F(.)$ depends on the distribution of the random term λ_i, hence, if γ_i' is normal, then $F(.)$ is a cumulative normal.

7.3 Empirical Model

The probability that a household will adopt improved soil and water conservation technology is expressed as a function of the cumulative distribution function of the disturbance term evaluated at $\beta' X_i$ in equation (7.3). The exact distribution of the cumulative distribution function $F(.)$ depends on the distribution of the random term. Depending on the assumed distribution that the random term follows, several choice models such as linear probability model, logit model, probit model or Tobit model could be estimated.

However, though the linear probability model is simple and easier to compute and interpret as compared to the other three qualitative choice models, its specification involving the application of ordinary least squares (OLS) create problems such as hetroscedasticity error terms, predicted values may fall outside the (0,1) corner solution interval and non normal distribution of the error term. Although transformation could give homoscedastic error terms and then apply weighted least square for estimation, there is no guarantee that the predicted values lie in (0, 1) probability range (Green, 2000).

The other three qualitative choice models, logit, probit, and Tobit have desirable statistical properties, as the predicted values of their probabilities lie in (0, 1) range and are widely used to assess the probability of using improved soil and water conservation technologies (Shiferaw and Holden, 1998; Lapar and Pandy, 1999; Bekele, 2003; Anley *et al*, 2007). However, knowledge of whether a farmer is using a given soil conservation technology based on binary responses as in the case of logit and probit models may not provide full and sufficient information about the farmer's behaviour because, he/she may apply fully or partly the technologies on his farm. In such situation, possible loss of information may occur if a binary variable is used as a dependent variable (Baidu-Forson, 1999).

Therefore, a strictly dichotomous variable often is not sufficient for examining the extent and intensity of use of technologies (Feder *et al.*, 1985). When the dependent variable is truncated and thus continuous between a certain lower and upper limit, the Tobit model is superior to probit and logit models. The probability and intensity of using improved soil conservation technologies are censored continuous variable due to the fact that not all sample households constructed improved soil and water conservation structures or those households who have constructed improved soil and water conservation structures have not done so on all of their farm plots. The extra advantage of this model as compared to the Probit and Logit models is that it reveals both the probability and intensity of using a technology. This implies that the binary choice dependent variable should be translated in to a continuous one. This approach is followed to model the adoption of improved soil and water conservation technologies in the study area.

A solution to the problem with censoring at zero (corner solution) was first proposed by Tobin in 1958 (Green, 2000) as the censored regression model which is called the Tobit model. Tobit model assumes a latent variable (y_i^*), which is not observable, as a linear function of a vector of explanatory variables and a disturbance term. Given, the latent variable y_i^*, the general formulation of the observed dependent variable y_i in the Tobit model is usually given as an index function (Green, 2000).

$$
\begin{aligned}
& y_i^* = \beta' X_i + \gamma_i \\
(7.4) \qquad & y_i = 0 \; if \; y_i^* \leq 0 \\
& y_i = y_i^* \; if \; y_i^* > 0
\end{aligned}
$$

Where x_i is a vector of factors affecting the use and intensity of use of improved soil and water conservation measures, β represents a vector of unknown parameters to be estimated, and γ_i is a random disturbance term that is independently and normally distributed with zero mean and constant variance, σ^2.

Analysis of the changes in the probability as the independent variable x_i changes is based on the Tobit likelihood function. The likelihood function is given as a combination of the probability function for non-adopters $y_i^* \leq 0$ and the normal density for the continuous part of the data (the density for adopters) and the model coefficients can be estimated by maximizing the Tobit likelihood function. The probability function for non-users of soil and water conservation technologies and the density function for the positive values of y_i (users of soil and water conservation technologies) could be specified respectively as follows (Green, 2000):

(7.5) $$pr(y_i^* \leq 0) = pr(y_i = 0) = \Phi \frac{(\beta' X_i)}{\sigma}$$

(7.6) $$f(y_i \mid y_i^* > 0) = \frac{f(y_i)}{pr(y_i > 0)} = \frac{\frac{1}{\sigma}\phi\left(\frac{y_i - \beta' X_i}{\sigma}\right)}{\Phi\left(\frac{\beta' X_i}{\sigma}\right)}$$

Where $\Phi(\cdot)$ and $\phi(\cdot)$ are, respectively, the standard normal cumulative distribution and the density function, which represent the truncated regression model for those observations greater than the threshold level of soil conservation measures, i.e., adopters. The log-likelihood function for the Tobit model is given as the summation of the probability functions for both adopters and non adopters.

(7.7) $$\ln L = \sum_{y_i^* \leq 0} \ln\left(1 - \Phi\left(\frac{\beta' X_i}{\sigma}\right)\right) + \sum_{y_i^* > 0} \ln\left[\frac{1}{\sigma}\phi\left(\frac{y_i - \beta' X_i}{\sigma}\right)\right]$$

For the index or latent variable $E\left[y_i^*\right]$ is equal to $\beta' X$ and the marginal effects of the Tobit model are given by:

(7.8) $$\partial E\left[y_i^* \mid X_i\right] / \partial X_i = \beta$$

But the marginal effect of Tobit model can not be directly interpreted in the same way as one interprets the coefficients in an uncensored linear model as the estimated coefficients are the marginal effect of a change in explanatory variable x_i on the unobservable latent variable y_i^*. Since y_i^* is not observed, this result is not of our interest. Hence, one has to compute the derivatives of the estimated Tobit Model to predict the effects of changes in the exogenous variables for the observed data, y_i. For the standard case with censoring at zero and normally distributed disturbance term, the result can be given as:

(7.9) $$\frac{\partial E[y_i \mid X_i]}{\partial X_i} = \beta\Phi\left(\frac{\beta' X_i}{\sigma}\right)$$

McDonald and Mofitt (1980) suggested a way of decomposition of marginal effects of the explanatory variables, $\partial E[y_i \mid X_i] / \partial X_i$, into the probability of use and intensity effects as follows:

(7.10) $$\frac{\partial E[y_i \mid X_i]}{\partial X_i} = \beta\left\{\Phi_i\left[1-\lambda_i(\alpha_i+\lambda_i)\right]+\phi_i\left(\alpha_i+\lambda_i\right)\right\}$$

Where $\Phi_i = \Phi\left(\frac{\beta' X_i}{\sigma}\right) = \Phi(\alpha_i)$ and $\lambda_i = \frac{\phi_i}{\Phi_i}$

Taking the two parts separately, this result decomposes the slope vector in to two:

(7.11) $$\frac{\partial E[y_i \mid X_i]}{\partial X_i} = pr[y_i > 0]\frac{\partial E[y_i \mid X_i, y_i > 0]}{\partial X_i} + E[y_i \mid X_i, y_i > 0]\frac{\partial pr[y_i > 0]}{\partial X_i}$$

The marginal effect of a variable x_i, on the probability of adopting improved soil and water conservation technology is:

$$\frac{\partial p_j}{\partial x_i} = f(\alpha' X).\alpha_j$$

Where $f(.)$ is the marginal probability density function of λ_i. Clearly the direction of the marginal effect is determined by the sign of α. But, since $\alpha' = \beta_1' - \beta_0'$, α is expected to be positive, negative or zero. Thus, a change in x_i (explanatory variables) has two effects. It affects the conditional mean of y_i^* in the positive part of the distribution (i.e. $y_i^* > 0$) and it affects the probability that the observation will fall in that part of the distribution (Green, 2000). The total change in the unconditional expectation is disaggregated in to the change in conditional intensity of use weighted by the probability of use and the change in the probability of use weighted by the conditional intensity of use.

The Tobit model assumes that a variable that increases the probability of using a given technology will also increase the mean amount used. However this assumption has to be tested to make sure whether the same set of explanatory variables affects both the decision to use and intensity of use of improved soil and water conservation technologies. In this analysis, two assumptions are made: the first assumption is that the same set of explanatory variables influences both the decision to use and intensity of use of ISWCT.

Obviously, the sample is not truncated, i.e., the sample is drawn from the whole population (not from a subset of the population). The first assumption is that there is no incidental truncation or farmers who use ISWCT do not self select and it is random, hence, the sample is a good representative of the whole population. In the second case, the first assumption is relaxed and it is assumed that there might be incidental truncation. Farmers who use ISWCT may self select and farmers' being users of ISWCT is not random implying that there is sample selection bias. In this case, Heckman's selection correction model (using full maximum likelihood, FML, estimation) is appropriate. However the likelihood ratio test of independence equations (rho = 0): $\chi^2(1)=1.45$; Prob > χ^2 = 0.2282 is not significant, hence the proposition that the same explanatory variables influence both the probability and intensity of use of ISWCT as well as the first assumption that there is no selectivity bias are not rejected. Therefore, results only from Tobit model are discussed in the next section.

7.4 Data and Variables Used in the Model

This study is based on primary data collected in 2007/2008 from a stratified proportionate random sample of 196 farm households in Anjeni area, northwestern Ethiopia. The definition and measurement of variables used in the econometric model are presented in table 7.1. Farmers' decision to use and the extent of use of improved soil and water conservation measures is influenced, among others, by the combined effect of a number of socioeconomic variables, household resources and farm plot characteristics related to farmer' objectives and constraints. Data collected for this study include demographic and socioeconomic characteristics of sample households as well as plot level data, farm resource use and soil conservation activities.

A total of 11 variables expected to affect the use of improved soil and water conservation measures in Anjeni area were hypothesized and included in the econometric model. Farm size is included in the analysis to test the assumption that the likelihood of using improved soil and water conservation technologies declines as the area of land becomes smaller and fragmented. When the area of a farm plot become smaller and smaller (more fragmented), farmers operating on small farm plot becomes less interested to construct soil conservation measures. Therefore, it is anticipated that land size and the likelihood of using improved soil conservation technologies are negatively correlated.

The available farm land relative to family labour force in a household is also included to see its effect on the use of improved soil and water conservation measures. The effect of land to labour ratio on the use of improved soil and water conservation measures is indeterminate a priori because it may have two effects. First, households with less land relative to labour may have enough labour input to construct improved soil and water conservation measures. On the other hand, the potential loss of land to soil conserving structures may discourage them from using soil conserving structures on their small per capita land holding. For households with more land per unit of labour, this potential loss of land and the subsequent reduction in cropping area may be less of a constraint relative to those with little land. Hence households with higher land to labour ratio are more likely to use improved soil and water conservation technologies.

The age of farm household heads are expected to influence the use of improved soil and water conservation measures. Age of the household head in years was used as an indicator variable for farming experience of the household head. Through experience, farmers may perceive and analyze the problem of soil erosion and develop confidence to use soil and water conserving measures. On the other hand younger farmers are motivated, more flexible and open to new practices. Therefore, the effect of age is indeterminate a priori.

Education level of household heads categorized by the number of years of formal and informal education completed was included. It is expected that farm household heads that have greater year of schooling are more likely to use improved soil and water conserving technologies. Because educated farmers can better understand, analyze, and interpret the advantage of different agricultural technologies compared to uneducated farmers.

Table 7.1: Definitions and measurement of variables used in Tobit model

Variables	Description and units of measurements
In (ISWCT)	The dependent variable, the natural log of improved soil and water conservation technology measured in meter per hectare
FARMSIZE	Farm size measured in hectare
FARM-LABOUR	The ratio of farm size in hectare to family labour measured in man-day
LIVESTOCK	Livestock owned measured in tropical livestock unit (TLU)
DISTANCE	Walking distance of the farm plot from home measured in minutes
SLOPE	Slope of a farm plot measured as a binary variable: 1 if the slope of the farm plot is steep (>10%), 0 otherwise.
AGE	Age of the household head measured in years
OFF-INCOME	Off-farm income measured in Ethiopian Birr(ETB)
BASIC-EDU	Basic education of the household head measured as a binary variable: 1 if the head of the household has religious/adult education; 0 otherwise.
PRIM-EDU	Primary education of the household head measured as a binary variable: 1 if the head of the household has primary education; 0 otherwise.
EXTENSION	The frequency of contact with extension agents during the past two years 1 if farmer had contact during the past two years; 0 other wise
PERCEPTION	Perception about the problem of land degradation measured as a binary variable: 1 If the farmer perceived the problem of land degradation, 0 otherwise
LOCATION	Location of the household measured as a binary variable: 1 if the household is located in upper Anjeni, 0 otherwise
TENURE	Attitude towards land tenure security measured as a binary variable: 1 if the farmer feels that he is secure to use his farm land in the future (no government take over for redistribution), 0 otherwise

Plot characteristics such as slope and distance from residence (home) are also considered to see if they have a significant effect on the use of improved soil and water conservation measures. The expectation is that high erosion potential on steeper slopes forces farmers to implement improved soil and water conservation measures. Similarly

farmers whose plots are nearer to their residence use soil-conserving technologies because the time and energy they spend is lesser for nearer plot than distant plots.
Other variables considered in the model include: availability of extension service, livestock holding of the household measured in tropical livestock units (Storck *et al*., 1991), tenure security, off farm income and the perception of the farm household head about the serious threat of soil degradation. Extension service provides the necessary information to acquire new skills and knowledge to farmers to improve soil conservation efforts. It is, therefore, expected that access to extension education to farmers and using soil conserving practices or technologies be positively correlated.

More specialization into livestock away from cropping may also reduce the economic impact of soil erosion and lower the need for soil conservation. On the other hand, those farmers who have large number of livestock may have more capital to invest in soil conservation practices. This affects the use of soil and water conservation measures positively. However, in the case of Anjeni area, conservation technologies are more labour intensive and require less capital. Therefore, the size of livestock holding is expected to affect conservation investment negatively.

It is also expected that farmers make fewer long-term land improvements if they feel that the government in the future will redistribute land. The presence of tenure security may increase land improvement practices. Therefore, long term land ownership confidence (land security) and soil conservation efforts might be positively correlated.

The expected effect of return to off-farm activity on soil and water conservation is ambiguous. On the one hand, better returns to off farm activity means competition with on-farm investment in terms of labour input. On the other hand, greater off-farm income means more cash available to the household to invest on farm. But labour and cash diverted to off-farm uses might also reduce the pressure on the land. It would provide cash to buy food and might encourage the household to use land in a less labour demanding ways, such as perennial crops, fallow and pasture.

7. 5 Results and Discussions

7.5.1 Soil and Water Conservation Practices in Anjeni Area

Farmers in the study area use both traditional and improved soil and water conservation methods. They employ traditional practices with no technical specifications, and hence much variability in application is observed. The most commonly used traditional soil conservation measure is traditional ditches (*feses*). Traditional ditches are constructed every cropping season and run diagonally over cultivated lands. Farmers indicated that the main purpose of traditional ditches is to drain water especially from *Teff* fields and protecting the flood that comes from uplands. However discussions with development agents and farmers indicated that traditional ditches are less effective in terms of protecting erosion as they are constructed diagonally on loosen soils.

Improved soil and water conservation technology employed and promoted in Anjeni area include improved soil bund, stone bund and *fanaya juu*. However, both the number of farm plots having improved soil and water conservation measures and the level or intensity of improved soil and water conservation technologies is very low. As shown on table 7.2, 51.5 percent of farm plots have improved soil and water conservation measures constructed on them.

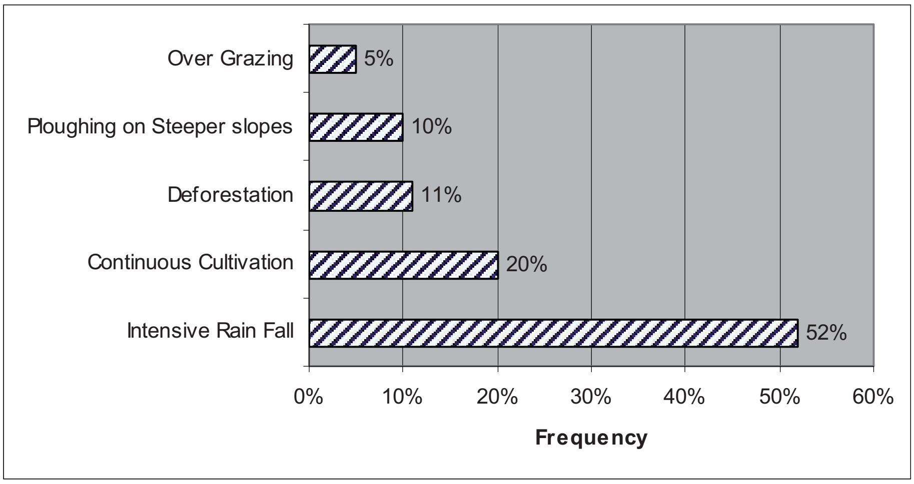
Table 7.2: Farm plots with soil and water conservation technologies (ISWCT)

Location		Percent of farm plots on:		
		Flat/gentle Slopes (0-10%)	Steep/rolling Slopes (>10%)	All slopes
Upper Anjeni	With ISWCT	30.8	69.2	56 .0
	Without ISWCT	52.0	48.0	44.0
Lower Anjeni	With ISWCT	37.5	62.5	45.0
	Without ISWCT	41.6	58.4	55.0
Total	With ISWCT	33.4	66.6	51.5
	Without ISWCT	47.0	53.0	48.5

Source: Own household survey (2007)

Only 19.3% of the farm plots (15% in upper Anjeni area and 27% in Lower Anjeni area) had improved soil and water conservation measures based on the recommended[1] rate of use. About 43.7% of farm plots (44% in upper Anjeni and 39 % in lower Anjeni area) have 50% and less rate of use of improved soil and water conservation measures. The perception of sample household heads about the primary causes of soil erosion is given in figure7.1 and a summary of descriptive statistics of sample households is presented in table7.3.

Figure 7-1: Farmers' perception about the primary causes of soil erosion



Source: Own survey (2007)

Results from sample respondents also revealed that nearly all farmers (98%) were aware of soil erosion process though they have different level of perception on primary causes of soil erosion and its impact and seriousness of soil erosion on productivity of land. Most farmers mentioned that intensive rainfall and continuous cultivation as the primary causes of soil erosion. Though field observation showed that erosion is more evident on steeper slopes, only 10% of farmers mentioned cultivation on steeper slopes as the primary causes of yield reduction in Anjeni area.

[1] The recommended average lengths per hectare of ISWCT by the MoARD are: 580 m/hectare on plots up to 10 % and 850 to 2500 meter/ha on slopes ranging between 10 and 50 % slopes.

Table 7.3: Descriptive statistics of the variables used in the model

Variable	Mean	Std. Dev	Min	Max
In (ISWCT)	3.073	3.03	0	7.848
FARMSIZE	1.043	0.35	0	2.125
FARM-LABOUR	0.424	0.28	0	2.8
LIVESTOCK	4.653	2.4	0	13.11
DISTANCE	15.403	16.12	0	90
SLOPE	0.60	0.5	0	1
AGE	45.00	13.73	18.0	80.0
OFF-INCOME	54.35	222.20	0	2000
BASIC-EDU	0.55	0.6	0	1
PRIM-EDU	0.15	0.46	0	1
EXTENSION	1	0.64	0	4
PERCEPTION	0.88	0.33	0	1
LOCATION	0.56	0.49	0	1
TENURE	0.62	0.49	0	1

Source: Own household survey (2007)

7.5.2 Factors Influencing the Use of Improved Soil and Water Conservation Technologies

The results from Tobit model estimation are presented in table 7.4. The Tobit regression model for predicting factors influencing the use of ISWCT is statistically significant at $p<0.01$ (LR $\chi^2(13) = 200.52$).The signs of the coefficient estimates of all the variables confirm prior expectations.

However some of the coefficients of the independent variables had no statistical support for the hypothesis. Significant variables in the model that influenced the decision to use and intensity of use of ISWCT Include: size of farm land (FARMSIZE), ratio of land to labour (FARM-LABOUR), slope of farm plot (SLOPE), age of the household head (AGE), primary education (PRIM-EDU), perception of farmers about the problem of land degradation (PERCEPTION).

Area of cultivated land positively and significantly influenced the probability and intensity of use of ISWCT. As the area of farm land becomes smaller and fragmented it is likely that farmers don't want to scarify a fraction of their land to construct physical soil conservation structures. Holding other variables at their mean, an increase of 1 ha in the size of farm land would increase the probability and intensity of use of ISWCT by 18.2% and 90.7% respectively. This contradicts with a study in Tigray region of Northern Ethiopia by Berhanu *et al*. (1999). They found out that larger fields have fewer fields of terracing per hectare because of terrace indivisibility and diminishing marginal returns to terrace density. The possible explanation in our case might be that ISWCT takes some fraction of farm land. Those farmers with very small and fragmented farm land may not want to scarify a fraction of their farm land to be occupied by improved soil and water conservation structures. Farmers with larger farm size may afford to allocate some part of their farm land to soil ISWCT compared to farmers having smaller size of cultivated land.

Table 7.4: Maximum likelihood estimates using Tobit model

Variables y=ln(ISWCT)	Coef. (Std. Err.)	Probability of use	Intensity of use
		$\partial(p(y>0))/\partial x$	$\partial(E(y\|y>0))/\partial x$
FARMSIZE	2.205** (0.649)	0.182	0.907
FARM-LABOUR	-3.489** (0.973)	-0.289	-1.435
LIVESTOCK	-0.025 (0.087)	-0.002	-0.010
DISTANCE	-0.001 (0.011)	-0.00004	0.0003
SLOPE	0.906* (0.388)	0.075	0.369
AGE	-0.065** (0.016)	-0.005	-0.027
OFF-INCOME	-0.001 (0.001)	-0.0001	0.0003
BASIC-EDU	0.81 (0.458)	0.067	0.332
PRIM-EDU	1.839* (0.617)	0.146	0.821
EXTENSION	0.232 (0.294)	0.019	0.095
PERCEPTION	7.876** (0.889)	0.556	2.314
LOCATION	1.632** (0.401)	0.135	0.661
TENURE	0.693 (0.392)	0.058	0.282
CONSTANT	-6.619 ** (1.398)		
Log-likelihood	-1506.9064		
LR $\chi^2(13)$	195.77**		**P<0.01, *p<0.05
No. of obs	812		
Left C at y<=0	394(48.5%)		

Land to labour ratio negatively and significantly influenced the probability and intensity of use of ISWCT. An increase of 1 unit in land to labour ratio of a farm household would reduce the probability and intensity of use of ISWCT respectively by 28.9% and 143.5%, holding other variables at their mean. This is because less amount of labour relative to farm size puts heavy burden on farmers. This result is in consistent with the Boserup hypothesis that as population grows relative to land resources, farmer must work more and more hours for the same amount of produce or intensification (Boserup, 1965 in Baidu-Forson, 1999).

The probability and intensity of use of ISWCT declines with age. Younger farmers exert more effort on the construction of ISWCT compared to farmers who are not so young. Holding other variables at their mean, a 10 years[1] increase in age of a farmer decreases the probability and intensity of use of ISWCT approximately by 5% and 27% respectively. The possible explanation might be that younger farmers assume longer planning horizon relative to those farmers who are not so young. In addition to farmers who are not so young may tend to have conservative outlook towards new technology.

Slope of a farm plot positively and significantly affect the probability and intensity of use of ISWCT. Holding other variables at their mean, the probability of using ISWCT among non users and the intensity of use of ISWCT among users would by higher respectively by 7.5% and 36.9% on plots having steep slope compared to plots having gentle slopes. The specific results are consistent with the hilly and rugged terrain of the study area. More than 60% of the farm plots in Anjeni area have steeper and rolling slope. The significant positive terms indicates that farmers are inclined to invest in conservation practices where their farm plots are located on steep slopes.

Primary education, as expected, positively and significantly affects the probability and intensity of use of ISWCT. The chances of investing in ISWCT among non users would be higher by 14.6% for a farmer who has a formal education compared to a farmer who has no education at all. Similarly, the intensity of use of ISWCT would be higher by 82.1% for a farmer who has a formal education compared to a farmer who has no education at all. However, the probability of using ISWCT among non users wouldn't

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[1] Assuming that the relationship between age and the probability of using ISWCT is linear, we can multiply the marginal effect of age on probability by 10 to get the amount of change over 10 years.

significantly different for a farmer who has an informal education compared to a farmer who is an illiterate. Farmers with basic education are not significantly different from illiterates with respect to the decision to use and intensity of use of ISWCT. Those farmers with formal education are more open and ready to understand new ideas and concepts provided by extension workers and other informants. This underlines the importance of universal primary education for promoting new technologies to combat poverty and food security. However, basic or informal education, such as religious education and adult education programs, despite their advantage in other circumstances, do not have any significant effect on the use of ISWCT.

As expected the perception of the severity of land degradation problem by farmers positively and significantly influenced the use of ISWCT. The probability and intensity of use of ISWCT would be higher, respectively by 55.6% and 231.4% for farmers who have perceived that land degradation is a serious threat to their land compared to those who have not. This is true because, since land degradation is a gradual process and some farmers can't even imagine how serious the problem is, they may not appreciate the use of ISWCT.

The chances of investing in ISWCT would be higher by 13.5% for a household in Upper Anjeni area compared to a household in Lower Anjeni area. Similarly, the intensity of use of ISWCT would be higher by 66.1% for a household in Upper Anjeni area compared to a household in Lower Anjeni area, holding other variables at their mean. This could be explained by the fact that SCRP site is located in Upper Anjeni area and much more demonstration and on farm experiments were carried out in Upper Anjeni area compared to lower Anjeni area. Moreover, the relative nearness of upper Anjeni area to road and its convenience for development workers to visit the area more frequently than the lower Anjeni area have significant effect on the use of ISWCT.

7.6 Conclusions

In terms of maintaining or improving the productivity of agricultural land by small holder farmers and ensuring food security through increased food production, the results of the econometric model, in general, imply that the use and extent of use of improved soil and water conservation technologies largely depends on the resource constraints and the capacity and level of understanding of farm households. Policy Interventions and agricultural development programs that seeks to address farmer's resource constraints, empower their capacity and promote their understanding may result in positive and significant effect on promoting soil and water conservation and sustaining agricultural productivity.

More specifically, the results show that as the area of farm land becomes smaller and fragmented it is likely that farmers don't want to scarify a fraction of their land to construct improved physical soil and water conservation structures. This suggests that the ministry of agriculture and other stake holders may look for alternative soil and water conservation techniques in areas with small per capita land holding that may take relatively smaller fraction of farm land.

Exposure of farmers to formal education has influenced them to use and intensify ISWCT. This underlines the importance of investment in primary education not only to promote ISWCT but also help them understand and practice other types of improved agricultural technologies in rural areas.

Though farming experience is believed to be important in using improved agricultural techniques, the result of this study showed that the use of ISWCT declines with age. This suggests that the level of effort on training and extension service can be effectively utilized and its impact on technology promotion can be maximized if younger farmers and farmers who are not so young are targeted differently in training and demonstration.

CHAPTER EIGHT

SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

8.1 Summary

Land degradation due to soil erosion and soil nutrient depletion has contributed to declining agricultural productivity, poverty and food insecurity in the high lands of Ethiopia. Though, the introduction and promotion of improved soil and water conservation measures started in the 1980s and 1990s, the process of human-induced land degradation in Ethiopia is a long phenomenon and its causes are deeply rooted in its geography, agro-climatic factors, socioeconomic conditions and political history.

High rate of population growth on one hand and declining in the productivity of agricultural land on the other hand are widening the gap between food supply and food demand and threatening the livelihood of small scale subsistent farmers. Limited use of improved soil and water conservation measures, high costs of and limited access to agricultural inputs, continuous cropping on slopping and marginal lands and other socio economic conditions deprived farmers of incentives to improve land management and their livelihood. Misguided development policies, population pressure, fragmented land holdings and insecure land tenure are considered to be the underlying causes of land degradation in Ethiopia. The fragmented land holding system and the current insecure land tenure along with the economic conditions of farmers do not allow for a large-scale application of purchased inputs that would compensate the loss of nutrients and ameliorate the physical damage that is caused by soil erosion.

The current situation of land degradation, poverty and food insecurity in Ethiopia is so critical that there is a strong need to enhance agricultural production, productivity and food security through appropriate research, development and technological interventions. Soil erosion by water coupled with soil nutrient depletion in the highlands, might lead to irreversible changes in soil productivity that directly affects the food security situation of small farmers who are extremely dependent on their land and rainfall and cannot support further deterioration of soil productivity. Hence, promoting the use of improved soil and water conservation measures and other policy measures and technology interventions are crucial to counter land degradation process and to improve the productivity of land and income of small farm households.

Due to the continuous dependency on agriculture, land degradation and unfavorable climatic conditions, rural development policies in Ethiopia are challenged by two important issues: the need to improve household income to meet the demand for food in the face of growing population and the need to improve or sustain the productivity of agricultural land. To improve agricultural production and productivity, the agricultural systems should depend on conducive policy and technology environments. This highlights the important task of undertaking development research to understand the impact of different policy incentives and technology interventions to help policy makers understand the potential impacts of different policy incentives and technology interventions on sustainable land management, poverty and food security of small farm households.

Moreover, continuing land degradation can be counteracted by investment in improved soil and water conservation technologies, but depends on the willingness to adopt these technologies by the farmers. In response to the extensive degradation of its resource base, Ethiopia has undertaken some efforts to mitigate the problem of soil erosion and improve the productivity of the agriculture sector. Improved soil and water conservation technologies were introduced and promoted in some degraded area of the highlands including Anjeni area in the north western part of Ethiopia in the 1980s and 1990s. Various agricultural extension programs were undertaken to reduce soil erosion and improve agricultural productivity by disseminating different agricultural technologies, including soil and water conservation technologies. Despite the benefit, farmers appear to be sluggish to use improved soil and water conservation technologies and the adoption and diffusion of improved soil and water conservation technologies has remained limited or sub-optimal.

Therefore, the general objective of this study is to evaluate the effect of policy incentives and technology on land management and income of small farm households and to assess factors that influence the use of improved soil and water conservation measures by small holder farmers in Anjeni area, North western Ethiopia.

Evaluating different policy measures and technology interventions may be undertaken at different levels and the linkage between soil degradation and production is considered to be critical both for assessing the damages caused by land degradation and for evaluating the benefits from soil conservation measures. In this study, the analysis is undertaken at household level as the production and land management decisions are made at household level. While there is a strong interaction between the biophysical and socioeconomic decision making processes at household/farm level, the interaction between the biophysical and socioeconomic processes become more difficult to model at higher levels.

To attain these objectives, both primary and secondary data were collected from Anjeni area, north-western Ethiopia, from the Ministry of Agriculture and Rural Development and other national and international organizations. The study area was chosen because of problem of land degradation in the area and its representativeness to the rain-fed, cereal based, smallholder ox-plough farming system, which comprises significant proportion of the highlands of north-western Ethiopia. The primary data were collected from a total of 196 farm households selected based on stratified proportionate random sampling procedure and the biophysical data for Anjeni area, collected by soil conservation research project (SCRP) is used in this study.

The analytical approach used in this study is based on a bioeconomic modelling framework to evaluate the effect of policy incentives and technology interventions on land management and income of small farm households and an econometric model to assess factors that influence the use of improved soil and water conservation measures by small holder farmers in Anjeni area, North western Ethiopia.

The bioeconomic modelling framework incorporates both biophysical and socioeconomic components. The interaction between biophysical process, resource use, technology and allocation of other factors of production is captured by the production function. Soil quality is included as a determining variable in the production function, soil degradation is considered as a cause of yield decline and erosion is considered as the major process contributing to soil degradation. The modified universal soil loss equation (USLE) adapted to the Ethiopian conditions is used to estimate the rate of soil loss from different land class categories in the study area to understand the impact of soil erosion on soil nutrient balance (soil quality) and crop yield. Since one of the main objectives is to evaluate the effects of different policy incentives and technology on the quality of soil in Anjeni area, the Nutrient Monitoring (NUTMON) model is used to assess soil nutrient balance.

In this study, a linear programming model that maximizes the expected income of farm households subject to resources and other technical constraints is employed. The linear programming optimization procedure is used as a method for the appraisal of farm households' response to technology interventions and policy incentives. The study also considered down side risk associated with rainfall and yield variability. Small holder farming in the study area is rain-fed and Land degradation and lack of adequate (erratic) rainfall often causes crop failures. Farmers struggle for their very existence and typically behave in risk-averse ways and they often prefer production options that can provide a good level of livelihood security. Thus, the Low's safety first model which selects the farm plan that has an income equal to or greater than some minimal income level in every state of nature and that maximizes expected income were incorporated in the model.

A positive mathematical programming technique is used to calibrate the linear programming model to overcome a situation in which the empirical constraint set does not reproduce the base results for lack of an empirical justification, data availability or cost of production. This method transcends the linear programming framework in that it introduces an artificial cost effect of the missing elements with the help of a non-linear variable cost (yield) function. This changes the linear programming into a Non-Linear Problem (NLP) and is commonly called Positive Mathematical Programming (PMP).

In addition to the bioeconomic model described in the previous paragraphs, this study also employed a Tobit model to explain why farmers appear to be sluggish to use improved soil and water conservation technologies and why the adoption of soil and water conservation technologies in Anjeni area has remained limited despite the fact that different studies indicated high expected benefit from using improved soil and water conservation technologies.

The bioeconomic model is validated and its sensitivity is tested for selected parameters before using the model to analyse the effect of policy measures and technology interventions on land quality and income of farm households under alternative scenarios. The model was run for two representative groups of households clustered based on factor analysis techniques. The two household groups differ in terms of land size, labour endowment and oxen ownership that are important constraints in production and land management decisions.

Different constraints are employed for each household group. The important model results considered and compared among different scenarios are soil nutrient (nitrogen) balance in the soil on four different types of land classes, an indicator of soil quality and household income, an indicator of household utility or welfare and resource use patterns. The specific policy and technology scenarios used in the simulation include: the effects of improved soil and water conservation technologies, access to credit and the use of improved crop variety and a combination of them.

The results of the model indicated that the effect of improved soil and water conservation measures on soil nutrient balance differs among the two groups of households as well as across different land types. For both household groups and different land classes, improved soil and water conservation measures could reduce soil erosion by more than 58%.The average rate of soil loss declines substantially as we move from land type S4 (sloppy and less fertile lands) to land type S1 (fertile and gentle slope lands).The amount of soil loss is relatively higher on land classes S3 and S4 as compared to S1 and S2 due to the combined effect of topography and physical property of soils on erosion.

Limited access to credit has a positive impact on income only for household group-I. Household group-II, who has relatively better working capital, is less responsive to this policy incentive. The apparent effect of credit on the income of household group-I is primarily due to its effect in financing the purchase of inputs that have direct impact on crop yield.

The combined effect of improved soil and water conservation measures, access to fertilizer credit and high yielding crop variety appear to have the highest impact on income and land degradation as compared to individual policy incentives and technology intervention scenarios as they address, simultaneously, several constraints of small farm households. This scenario increases the income levels by more than 7% for both household groups and reduces nutrient loss by more than 66% for both household groups on all land classes. However, these policy incentives and technology interventions can't, simultaneously, increase income and soil nutrient balance.

Farmers in the study area use both traditional and improved soil and water conservation methods. They use traditional soil conservation measures with no technical specifications, hence much variability in application is observed. The most commonly used traditional soil conservation measure is traditional ditches (*feses*). Traditional ditches are constructed every cropping season and run diagonally over cultivated lands. However discussions with development agents and farmers indicated that traditional ditches are less effective in terms of protecting erosion as they are constructed diagonally on loosen soils mainly to drain water away from farm plots. Improved soil and water conservation measures introduced and promoted in Anjeni area include improved soil and water bund, stone bund and *fanya juu*. However, both the number of farm plots with improved soil conservation measures and the intensity of use are very low.

The results from econometric model estimation indicate that the size of farm land, ratio of land to labour, slope of farm plots, age of the household head, primary education, perception of farmers about the problem of land degradation have influenced farmers' decision to use and intensity improved soil and water conservation measures in Anjeni area. Area of cultivated land positively and significantly influenced the probability and intensity of use of improved soil and water conservation measures (ISWCT). As the area of farm land becomes smaller and fragmented, it is likely that farmers don't want to scarify a fraction of their land for the construction of soil and water conservation structures. Farmers with larger farm size may afford to allocate some part of their farm land to ISWCT compared to farmers having smaller size of cultivated land. Land to labour ratio negatively and significantly influenced the probability and intensity of ISWCT. This is because less amount of labour relative to farm size puts heavy burden on farmers.

The probability and intensity of use of ISWCT decline with age. Younger farmers exert more effort on the construction of ISWCT compared to farmers who are not so young. The possible explanation might be that younger farmers are more innovative and assume longer planning horizon compared to those farmers who are not so young. Slope of a farm plot positively and significantly affect the probability and intensity of use of ISWCT. This indicates that farmers are inclined to invest in conservation practices where their farm plots are located on steep slopes. However, only small proportion of farm households uses the recommended rate of improved soil and water conservation measures.

Primary education, as expected, positively and significantly affects the probability and intensity of use of ISWCT. However, the probability of using ISWCT among non users is not significantly different for a farmer who has an informal education compared to a farmer who is an illiterate. Farmers with basic education are not significantly different from illiterates with respect to the decision to use and intensity of use of ISWCT. Those farmers with formal education are more open and ready to understand new ideas and concepts provided by extension workers and other informants. This underlines the importance of universal primary education for promoting new technologies to combat poverty and food security. However, basic or informal education, such as religious education and adult education programs do not have significant effect on the use of improved soil and water conservation measures. As expected the perception of the severity of land degradation problem by farmers positively and significantly influenced the use of ISWCT.

8.2 Conclusions and Policy Implications

Though the magnitude of the current and future impacts of soil erosion on the productivity of farm land is not known very well, the potential threat it poses on the livelihood of small farm households in the highlands of Ethiopia is not disputed. Thus, sustaining the quality of agricultural land through appropriate soil and water conservation techniques should be an important research, policy and development priority of different stake holders in Ethiopia where nearly 85 percent of the population depends on agricultural land for their livelihood.

The results of the bioeconomic-model, in general, indicate that the income of farm households can be improved and the rate of land degradation can be reduced via policy incentives and technology interventions. The introduction of improved soil and water conservation technologies could reduce land degradation significantly compared to the case without conservation. However, the use of physical soil and water conservation measures alone can't sustain crop yield as soil erosion can't be completely mitigated (only slowed down), suggesting that an integrated soil conservation approach, including biological and other soil conservation measures, should be adopted if farmers are to improve (sustain) land quality and crop yield.

The results of the model indicated that the short term return from the construction of improved soil and water conservation measures is negligible. However, the main concern or motivation of most smallholder farmers in the Highlands of Ethiopia is the short term family sustenance and daily survival of livelihoods implying that government institutions and non governmental organizations involved in the design and implementation of land conservation measures should have a mechanism to provide economic incentives to farmers to motivate them construct improved soil and water conservation technologies.

The result also indicated that access to fertilizer credit has different effect on the income of the two household groups. This implies that the importance of targeted intervention in providing credit access to small holder farmers. The modest impact of improved Wheat variety on income and the negative impact on soil nutrient balance suggest that improved crop varieties perform better along with technological packages such as fertilizer and soil conservation measures. Therefore, it is be important to link provision of credit for fertilizer to the use of improved seed, as this improve both household income and soil quality.

The combined effect of improved soil and water conservation measures, access to fertilizer credit and the use of high yielding crop variety appear to have the highest impact on income and quality of farmers' land as compared to other individual intervention scenarios. However, there are no win-win situations in all scenarios, i.e., policy incentives and technology interventions couldn't, simultaneously, increase both income and soil nutrient balance.

The model results also indicate that land is the most binding factor of production while the opportunity cost of labour is very low in Anjeni area. Given the low opportunity cost of labour and the scarcity of land, activities that require little/no amount of land, such as tree-planting activities on degraded lands and beekeeping activities, may provide opportunities to improve the income and welfare of farm households to offset the pressure on land from growing population. The low opportunity cost of labour also implies that farmers can take advantage of soil and water conservation investments by increasing targeted use of fertilizer and high yielding crop varieties to improve land productivity if they are given proper incentives for conservation.

However, despite the opportunities to improve the income of farm households and reduce land degradation in Anjeni area, these strategies seem unlikely solve the long-term poverty problem facing farm households. This implies that non-farm sector development and other employment opportunities have to be found in the medium and long term to improve the livelihood of farm households as the area has relatively better access to road and given the fact that there is high population density and land scarcity in the area. In the long term, such balanced development of both the farm and non-farm sectors would be the key to achieving more sustainable use of the land, economic growth and elimination of poverty.

The results in the above discussion indicated the relative importance of some of the variables included in the econometric model and the implication for policy and development strategies towards sustaining agricultural land through the use of improved soil and water conservation technologies. In terms of maintaining or improving the productivity of agricultural land by small holder farmers and ensuring food security through increased food production, the results of the econometric model, in general, imply that the use and extent of use of improved soil and water conservation technologies largely depends on the resource constraints and the capacity and level of understanding of farm households. Policy Interventions and agricultural development programs that seeks to address farmer's resource constraints, empower their capacity and promote their understanding may result in positive and significant effect on promoting soil and water conservation and sustaining agricultural productivity.

More specifically, the results show that as the area of farm land becomes smaller and fragmented it is likely that a farmer wouldn't want to scarify a fraction of their land to construct physical soil and water conservation structures. This suggests that the ministry of agriculture and other stake holders may look for alternative soil and water conservation techniques in areas with small per capita land holding that may take relatively smaller fraction of farm land.

Exposure of farmers to formal education has influenced them to use and intensify ISWCT. This underlines the importance of investment in primary education not only to promote ISWCT but also help them understand and practice other types of improved agricultural technologies in rural areas. Though farming experience is believed to be important in using improved agricultural techniques, the result of this study showed that the use of ISWCT declines with age. It seems that younger farmers are open to new ideas and practices. This suggests that the level of effort on training and extension service can be effectively utilized and its impact on technology promotion can be maximized if younger farmers and farmers who are not so young are targeted differently.

8.3 Study Limitations and Future Research

The first important limitation of this study is that only physical soil and water conservation measures promoted in Anjeni area are considered in the biophysical component of the model. The second limitation is that it didn't consider the inter-temporal trade-offs between sustainable land management and income of subsistence farming due to lack of consistent time series data relating biophysical process to socioeconomic conditions in Anjeni area.

In order to provide scientific information to the ongoing policy debate and policy incentives and technology interventions by different stakeholders, a number of future research areas and approaches can be proposed related to sustainable land management to improve the livelihood of subsistent farmers in the highlands of Ethiopia. First, it is important to examine the effect of different integrated land management options, especially, different soil and water conservation options in an integrated manner. Second, a more important approach for future research is to shift the analytical approach from static to dynamic modelling framework under different socioeconomic and biophysical environments to evaluate the inter-temporal trade of between sustainable land management and income of subsistence farming.

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APPENDICES

Appendix-1: Universal soil loss equation adapted to Ethiopia

The universal soil loss equation(USLE) for estimating average annual soil erosion is defined by the following equation (Wischmeirer and Smith, 1978):

A = RKLSCP;

Where:

A = average annual soil loss (tons per hectare); R = rainfall erosivity index;
K = soil erodibility factor; L= slope length;
S= slope gradient; LS = topographic factor;
C = land cover (cropping factor); P =land management /conservation factor

1.Rainfall Erosivity(R)								
▪ Rainfall(mm)	100	200	400	800	1200	1600	2000	2400
▪ Factor (R)	48	104	217	441	665	890	1115	1340
2.Soil Erodibility(K)								
▪ Soil Colour	Black		Brown		Red		Yellow	
▪ Factor(K)	0.15		0.20		0.25		0.30	
3.Slope Length(L)								
▪ Length(m)	5	10	20	40	80	160	240	320
▪ Factor (L)	0.5	0.7	1.0	1.4	1.9	2.7	3.2	3.8
4.Slope Gradient(S)								
▪ Slope (%)	5	10	15	20	30	40	50	60
▪ Factor(S)	0.4	1.0	1.6	2.2	3.0	3.8	4.3	4.8
5.Land Cover(C)								
Land Cover			Factor(C)	Land Cover			Factor(C)	
▪ Dense Forest			0.001	▪ Dense grass			0.01	
▪ Other forest			0.02	▪ Degraded grass			0.05	
▪ Bad Lands hard			0.04	▪ Fallow hard			0.05	
▪ Bad Lands soft			0.05	▪ Fallow ploughed			0.60	
▪ Sorghum, Maize			0.10	▪ *Teff*			0.25	
▪ Cereals			0.18	▪ Continuous fallow			1.00	
▪ Pulses			0.15					
6.Land Management(P)								
Land Management Type			Factor(P)	Land Management Type			Factor(P)	
▪ Ploughing up and down			1.00	▪ Dense cropping			0.70	
▪ Ploughing on contour			0.90	▪ Applying mulch			0.60	
▪ Strip cropping			0.80	▪ Stone cover (40%)			0.80	
▪ Intercropping			0.80	▪ Stone cover (80%)			0.50	

Source: (Hurni, 1988)

Appendix-2: Nutrient content of eroded soil at three level of soil fertility

Soil fertility class	Percentage of nutrients in eroded soil		
	N	P_20_6	K_2O
low	0.05-0.06	0.02	0.05
medium	0.1-0.15	0.05	0.1
high	0.15-0.2	0.1	0.2

Sources: Roy *et al*. (2003)

Appendix-3: Length and area covered with soil conservation measures

slope	Length (m/ha)	Base width of swc(m)			Area covered with soil and water conservation measures (ha/ha)		
		Soil bund	Stone bund	*fanaya juu*	Soil bund	Stone bund	*fanaya juu*
0-15 (10%)	660	1	0.6	1	0.066	0.039	0.066
15-30 (25%)	1250	1	0.6	1	0.125	0.075	0.125
> 30 (40%)	200	1	0.6	1	0.200	0.120	0.200

Source: Adapted from MOARD (2005)

Appendix-4: Labour requirement for soil and water conservation technology

Slope (%)	Distance b/n conservation structures (m)	Length of soil conservation Structures (km/ha)	Total labour required (MDs/ha)			
			Soil Bund	Stone Bund	Fanya Juu	Average
5	20	0.50	75.0	125.0	100.0	100
10	15	0.66	99.0	165.0	132.0	132
15	12	0.83	124.5	207.5	166.0	166
20	10	1.00	150.0	250.0	200.0	200
25	8	1.25	187.5	312.5	250.0	250
30	8	1.25	187.5	312.5	250.0	250
35	6	1.66	249.0	415.0	332.0	332
40	5	2.00	300.0	500.0	400.0	400
50	4	2.50	375.0	625.0	500.0	500

Source: Adapted from MOARD (2005)

Appendix-5: Conversion factors used to estimate tropical live stock units (TLU)

Animals	Calf	Heifer	Cows & Oxen	Horse	Donkey	Ship & Goat	Chicken
TLU equivalent	0.25	0.75	1.0	1.10	0.70	0.13	0.013

Source: Storck *et al*. (1991)

Appendix-6: Conversion factors used to estimate labour equivalent (man days)

Age group (years)	Gender	
	Male	Female
Below 10	0	0
10-13	0.2	0.2
14-16	0.5	0.4
17-50	1.0	0.8
Over 50	0.7	0.5

Source: Storck *et al*. (1991)

Appendix - 7: Chemical and physical properties of soils in Anjeni area

Major soil units	Area proportion (%)	Soil depth range (cm)	Bulk density g/cc	PH (H_2O; 1:2.5)	Cation exchange capacity (meq/100g)	Total Nitrogen (%)	Organic Carbon (%)	Plant available Phos-phorus (ppm)
Humic Alisols	19.32	65-200	1.00-1.60	5.4-5.7	26.0-38.8	0.2-0.3	1.8-2.7	2.7-6.9
Haplic Alisols	19.04	50-110	1.00-1.60	5.2	29.2	0.1	1.4	6.5
Humic Nitosols	15.90	100-200	1.07-1.23	5.7	28.4	0.2	1.7	2.3
Haplic Nitosols	6.10	50-150	1.04-1.20	5.3	27.0	0.3	2.4	4.8
Cambisols	17.47	70-100	1.00-1.60	5.0-5.3	27.8-32.8	0.2-0.4	2.2-3.6	0.9-4.6
Regosols	9.24	<25-50	1.08-1.15	5.3	28.6	0.1	1.4	2.4
Lixisols	4.44	100-150	1.00-1.60	5.7	24.2	0.2	1.2	4.9
Luvisols	3.88	120-150	1.06-1.09	5.5	26.2	0.2	1.5	3.3
Acrisols	2.40	100-150	1.00	5.5	24.6	0.2	1.1	3.7
Leptosols	2.22	<25-50	1.00	5.6	35.8	0.4	3.9	4.0

Source: Adapted from Kejela (1995) and Zeleke (2000)

Appendix-8: Residue to grain ratio of crops

crop type	Barley	*Teff*	Wheat	Beans	Pea
Residue to grain ratio	2.4	3.4	2.9	1.8	5.1

Source: (Dzowela, 1987)

Appendix-9 : Heckman selection model estimation

Variables y= ln(ISWCT)	Regression Equation		Selection equation	
	Coef.	z	Coef.	z
FARMSIZE	0.246*	2.01	0.568**	3.28
FARM-LABOUR	-0.561**	-2.62	-0.795**	-3.25
LIVESTOCK	0.019	1.21	-0.012	-0.54
DISTANCE	0.001	0.69	-0.001	-0.15
SLOPE	-0.015	-0.2	0.247**	2.53
AGE	0.003	0.96	-.017**	-4.16
OFF-INCOME	0.0001	0.63	-0.0002	-1.01
BASIC-EDU	-0.006	-0.07	0.2	1.74
PRIM-EDU	0.233*	2.09	0.421**	2.61
EXTENSION	0.061	1.15	0.041	0.53
PERCEPTION			1.705**	8.13
LOCATION	-0.078	-0.96	0.456**	4.47
TENURE	0.107	1.48	0.167	1.69
Constant	5.459**	23.6	-.670**	-4.88
No. Obs=812; censored= 394(48%); **P<0.01, *p<0.05 Wald $\chi^2(12)$ = 21.92* ; lambda= 0.175 LR test of indep. eqns.(rho = 0):$\chi^2(1)$=1.45; Prob > χ^2 = 0.2282				