CHAPTER I: INTRODUCTION

1.1 Background and motivation

Land degradation as a result of soil erosion and soil nutrient mining and their consequent negative effects on productivity, food security and well being of rural population are considered a fundamental problem in most sub-Saharan African (SSA) countries (Lal, 1995; Bojo, 1996; Brekke et al., 1999; Pagiola, 1999; Sonneveld and Keyzer, 2003; Nakhumwa, 2004).

In Ethiopia, soil degradation is recognized as one of the most important natural resource problems imposing on-site costs to individual farmers in terms of reduced yield and off-site costs to society as a result of externalities (Hurni, 1993; Sutcliffe, 1993; Bojo and Cassells, 1995; Shiferaw and Holden, 1998; Pender et al., 2001). A number of studies have shown that current soil loss rates on croplands stand between 42 and 100 ton/ha/year in the highlands leading to a productivity decline between 0.2 and 1.8 per cent per year (FOA, 1986; Hurni, 1993; Sutcliffe, 1993; Bojo and Cassels, 1995). Sutcliffe (1993) further noted that if soil erosion continues at current rates, over 6 million hectares of additional cropland and pasture in the Ethiopian highlands might become unusable by 2010. Similarly, estimated soil nutrient losses for the highlands of Ethiopia are high, exceeding 80 kg of N, P_2O_5, and K_2O per cultivated hectare (Stoorvogel and Smaling, 1990).

In Ethiopia where agriculture accounts for 50 per cent of GDP, 90 per cent of exports and 85 per cent of employment, agricultural intensification is a prerequisite for economic development (MEDaC, 1999). However, soil degradation has become the basic challenge constraining smallholder farmers from achieving an acceptable level of food security. Improved agricultural technologies (improved crop varieties, commercial fertilizers, better agronomic practices and pest control measures) have been promoted among smallholder farmers by government and non-government organizations (NGOs) in an attempt to address the declining agricultural productivity and improving food security.

However, despite these efforts, adoption of agricultural technologies by smallholder farmers across the country has remained below expectations (Yirga et al., 1996; Demeke et al., 1997; Alene, et al., 2000; Croppenstedt et al., 2003). As a result, the productivity of Ethiopian agriculture has remained one of the lowest in the world. Yield per hectare of cereals remained low at 1.2 tons per hectare compared with the global average of 4.0 tons per hectare (FAO, 1998). As a consequence, food availability per person has progressively declined (Zegeye and Habtewold, 1995; MEDaC, 1999).

Recognizing that the benefits from improved agricultural technologies would not be realized unless accompanied by soil conservation measures and prompted by the 1974 drought that caused devastation to the rural population, the government assisted by external donors launched a major public soil conservation (soil and stone bunds) works under the food-for-work program since the 1970's. However, adoption of both soil conservation and soil fertility enhancing practices such as commercial fertilizers have remained low (Yirga et al., 1996; Gebre Michael, 1999; Shiferaw and Holden, 1998; Gebremedhin and Swinton, 2003; Croppenstedt et al., 2003).

Farmer incentives to invest in soil conservation and soil fertility enhancement practices in Ethiopia and elsewhere in SSA countries have been constrained by a combination of unfavorable biophysical environment, population pressure, the institutional set up and short-term household objectives (Reardon and Vosti, 1995; Bojo and Cassells, 1995; Clay et al., 1998; Shiferaw and Holden, 1998; Pender et al., 2001; Sonneveld and Keyzer, 2003).

Population pressure has often been mentioned as one of the factors responsible for land degradation in Ethiopia (Grepperud, 1996; Pender et al., 2001; Sonneveld and Keyzer, 2003). The population of Ethiopia grew from 53 million in 1992 to 67.2 million in 2003 and expected to reach 129 million by 2030 (CSA, 2004). While population has continued to grow, growth in agricultural production declined from 0.7 per cent during the 1970-80 periods to 0.4 per cent in the 1980-92 period (World Bank, 1994)**.** The high population pressure in the Ethiopian highlands has led to land fragmentation as the available land have been redistributed to the increasing population over generations. Another issue linked to the soil degradation problem, the low level of adoption of soil conservation technologies and lack of interest in long term soil fertility maintenance practices is the insecurity of land tenure in Ethiopia (Adal, 2003; Rahmato, 2004). Prior to 1974 land reform, land tenure in Ethiopia was based on a feudal system where few landlords owned much of the land while the majority of farm households were tenants. Following the 1974 land reform, the then socialist government nationalized all rural land, ended all forms of tenancy, and distributed land to farm households based on family size (Stroud and Mekuria, 1992; Rahmato, 1984; Adal, 2000). However, farmers had only restricted usufruct rights but were not allowed to transfer their holdings in any form (inheritance, renting, share-cropping or gift). Land was re-distributed frequently in order to reduce landlessness as well as to address land quality differences until 1991. Following the fall of the socialist government in 1991, the new government introduced a series of political and economic reforms but land remained the collective property of all the people of Ethiopia under the custody of the government. Insecurity of land tenure has thus been and continues to be a major problem in Ethiopia.

Agricultural development policies have often been blamed to be unfavorable for the sustainable use of natural resources in Ethiopia. Domestic agricultural policies in the 1970s and 1980s discriminated against rural households by suppressing producer prices and forcing farm households to deliver a portion of their produce to the government controlled marketing institutions providing disincentive to the adoption of improved crop production as well as soil conservation practices (Franzel et al., 1992; Adunga and Demeke, 2000). The presumption that the country's food problem could be addressed through a quick fix of technological solutions also prompted government and donor agencies alike to adopt a technology transfer approaches focusing on short-term programs such as the development and transfer of improved crop production technologies. Besides, smallholder farmers primarily concerned with securing adequate food for their family immediate needs use low-external inputs and erosive farming techniques, which do not only mine the soil but also jeopardize the nations long-term food production ability. A recent study by Holden et al. (1998) suggested that smallholder farmers in SSA have very high rates of time preference, which partly explains smallholder farmers' reluctance to engage in long-term soil fertility and soil conservation practices.

1.2 Problem statement

Despite the seriousness of soil degradation problems (decline in soil quality due to water induced topsoil loss and net nutrient extraction) prevalent in Ethiopia and SSA countries, limited information and analyses have been carried out on the economic impact of soil degradation (Shiferaw and Holden, 2001; Brekke et al., 1999; Sonneveld and Keyzer, 2003). Knowledge of the technical relationship between soil loss and decline in crop yields was considered sufficient for formulation of sound conservation policy and hence the neglect of economic aspects of soil degradation control. Consequently, until recently, ecological effectiveness and technical simplicity had been a guiding principle in the design of soil conservation practices and policies in SSA including Ethiopia (Kapple, 1996).

As noted earlier, in SSA including Ethiopia, soil degradation is a pervasive problem posing a threat to current and future income and welfare of smallholder farmers as well as to national food security (Hurni, 1993; Sutcliffe, 1993; Bojo and Cassells, 1995; Bishop, 1995; Eaton, 1996; Shiferaw and Holden, 1998; Sonneveld and Keyzer, 2003). Farm households bear on-site costs associated with the control of soil degradation practices but gain very little from the off-site benefits generated as a result of their actions. These households may not be willing to invest in soil conservation suggesting the existence of a divergence between the private and social objectives concerning optimal levels of soil conservation. This divergence arises not only due to externalities but also because of insecure land tenure and market imperfections and limited access to input and output markets, credit, off-farm employment and information (Barbier and Burgess, 1992; Barbier, 1995; Holden et al., 1998; Holden and Shiferaw, 2004; Rahmato, 2004). It has been postulated in the economic literature that an individual farmer might not adopt the optimal path of soil use that a social planner would because the farmer's rate of time discount exceeds that of the social planner (McConnell, 1983; Reardon and Vosti, 1995;

Bishop; 1995; Barbier, 1995; Holden et al., 1998). The high time preference displayed by smallholder farmers is believed to be associated with poverty, risk aversion behavior and insecure land tenure (Barbier, 1995; Bishop, 1995; Shiferaw and Holden, 1999).

Economic theory also asserts that farmers in a perfectly competitive market use land in such a way that equates the marginal private cost of production with the marginal private benefit. In the presence of externalities, however, the social marginal costs will be greater than the marginal private cost of agricultural production realized by farmers suggesting that from society's point of view the soil capital is over utilized and that private and social optima diverge.

As has been pointed out, empirical studies that quantify and analyze the divergence between the private and social optima in the use of soil capital are quite rare in SSA including Ethiopia. Admittedly, an agricultural country such as Ethiopia need to adopt a long term and dynamic perspective to the soil erosion and soil-mining problem if the country has to conserve its fragile soil resources. Policy prescriptions based on short-term assessment of costs and benefits are highly unlikely to be optimal. Accordingly, the present study adopted a dynamic optimization framework in order to assess the inter-temporal trade-offs (the true social costs of soil loss relative to the value of output expected) that farmers face in their production decisions. The study therefore aims to determine and compare optimal levels of input use and production when the dynamic costs of soil erosion and mining are taken into account with static solutions when dynamic costs are ignored.

As argued above, use of organic and inorganic fertilizers and soil conservation practices remain low among smallholder farmers in Ethiopia. This study also attempts to analyze the incidence and intensity of use of alternative soil conservation and soil fertility management technologies and identify the factors influencing smallholder farmers' adoption decisions across agro-ecologies, farming systems, administrative boundaries and socio-economic groups.

The study aims to contribute to improved policy formulation and design through the identification of socio-economic factors that has constrained the adoption of soil conserving and soil nutrient enhancing practices by smallholder subsistence farmers. Knowledge about the dynamic costs of soil degradation is also useful for correcting the national income accounts to better reflect sustainable income.

1.3 Objectives of the study

This study has two main objectives. The first is to analyze the effect of ignoring the dynamic cost of soil erosion and soil nutrient mining in production decisions and resource allocation and use in Ethiopia. The second main objective is to analyze the incidence and determinants of intensity of use of soil conservation and soil fertility management practices in Ethiopia. Specific research tasks to be pursued under these two main objectives are:

1. Derive and compare optimal resource use and production levels under static and dynamic decision environments with respect to soil erosion and mining.
2. Measure the dynamic cost of soil erosion and the implications of not accounting for soil resource depletion on the country's economic welfare.
3. Assess the incidence and intensity of use of improved as well as indigenous soil fertility and soil conservation practices employed by smallholder farmers in the Central Highlands.
4. Examine the factors that condition farmers' choice (rate and intensity) of improved soil conservation measures and soil fertility management options in the Central Highlands.
5. Analyze policy implications and suggest ways of improving soil degradation control and soil fertility management practices.

1.4 Approaches and methods of the study

This thesis provides an analysis of the socio-economic aspects of soil degradation as it applies to smallholder subsistence farmers in the central highlands of Ethiopia. It employs mainly two analytical techniques to attain the stated objectives. The study first develops an optimal control model and then applies the model to quantify and compare the optimal levels of soil degradation under dynamic and static conditions. Second, the study estimates the incidence (rate) and intensity of use of soil conservation and soil fertility management practices to illustrate the spatial pattern of adoption across farming systems and socioeconomic groups. Technology adoption and diffusion models are used to analyze the factors that condition the rate and intensity of use of soil fertility and soil conservation practices by smallholder farmers in the Central Highlands of Ethiopia.

1.5 Organization of the thesis

The thesis is organized into nine chapters. The next chapter (chapter II) presents an over view of the agricultural setting of Ethiopia and its soil resources. Chapter III reviews the relevant literature on the economics of soil fertility management and soil conservation practices with due attention to the approaches used to measure and model economic costs and benefits of soil use and conservation. Chapter IV presents the study approach for modeling the dynamics of optimal use and extraction of the soil capital in Ethiopia. Chapter V is dedicated to describing the study locations, the research design and socio-economic characteristics of the sample households. The optimal control model developed in chapter IV is empirically specified and applied to the situation of smallholder farmers in the highlands of Ethiopia in chapter VI. Chapters VII and VIII are concerned with the analysis of the soil fertility and soil conservation adoption behavior of smallholder farmers in the highlands of Ethiopia. While chapter VII presents the analytical framework adopted by the study, chapter VIII applies the econometric models specified in chapter VII and discusses the results. The last chapter, chapter IX, provides a summary of the research problem, the study approach, the main findings and implication for policy and further research.

CHAPTER II:OVER VIEW OF THE AGRICULTURAL SECTOR, SOIL RESOURCES AND SOIL DEGRADATION IN ETHIOPIA

This chapter presents an overview of the agricultural sector and the conditions of soil resources in Ethiopia. The first section provides a summary of the performance of the agricultural sector focusing on trends in production and productivity. Section two describes the dominant soil resources of Ethiopia; examines the extent and severity of soil degradation; documents the effects of soil degradation on the development of the agricultural sector; and assesses the research and extension interventions implemented in the country to contain soil degradation. The third section offers an assessment of the economic policy environment that has shaped past and current efforts to contain soil degradation and bring about sustainable agricultural development in Ethiopia. The last section concludes by providing a summary.

2.1 Performance of the agricultural sector

Ethiopia with 1.12 million square km of total area is one of the largest countries in Africa exhibiting a considerable geographical variation with altitudes ranging from 125 meters below sea level in the Danakil to 4620 meters above sea level in the peaks of the Semien mountain ranges. Ethiopia is the second most populous country in Africa with 67.2 million people, of which about 89 per cent reside in rural areas (CSA, 2004). While about 66 per cent of the land is considered to be suitable for agriculture, only 16.5 million ha are estimated to be under cultivation in any one year (MEDaC, 1999). However, about 88 per cent of the human and 75 per cent of the livestock population are concentrated in the highlands, areas higher than 1500 meters above sea level, constituting 44 per cent of the land area of Ethiopia. The highlands also constitute about 95% of the cultivated area (Kruger, et al., 1996). Though land and labor are the two most abundant resources vital for its economic development, the fast growing population, currently estimated to be increasing at 2.9 per cent, and the current land use appear to be in disharmony threatening the sustainable use of its natural resources particularly that of land which forms the bases of livelihood for the majority of the population.

Poverty is pervasive in Ethiopia with an estimated 44 per cent of the population living under the poverty line (FDRE, 2000; World Bank, 2004). Economic growth has been stagnant, even declining during the socialist regime, which ruled the country from 1974 to 1991. For instance during the period 1982 to 1992, per capita gross domestic product (GDP) declined at a rate of 2.4 per cent per annum. However, following regime change and introduction of economic policy reforms in the 1990's, per capita GDP grew by an average rate of 5.5 per cent per annum (Table 2.1).

Agriculture is the mainstay of the economy contributing about 50 per cent of the gross domestic product (GDP), 85 per cent of the employment and 90 per cent of the export earnings (MEDaC, 1999). Agricultural products: coffee, oil seeds, pulses, hides and skins and recently chat (Catha edulis, a stimulant crop) constitute about 90 per cent of the export earnings. Coffee is the single most important foreign currency earner contributing about 60 per cent of the export earnings in any one year (MEDaC, 1999).

Despite its importance, the performance of the agriculture sector has been dismal. While population grew by 2.9 per cent per annum between 1980 to 1990, value added in agriculture and allied activities at 1980 constant factor cost grew by about 1.3 per cent which in effect meant a decline of 1.6 per cent per annum. This dismal performance of the sector was partly attributed to the poor policies of the socialist oriented military regime. The performance of the agricultural sector, however, did not improve much with the demise of the military regime. Since 1992, value added in agriculture and allied sectors have shown a modest growth of 2.8 per cent per annum (Table 2.1). And yet, apart from the services sector, which exhibited relatively better and consistent growth in the post reform period, the relative share of agriculture and industry of total GDP remained largely unchanged (Figure 2.1). The fact that there has not been any perceptible growth in the other sectors meant that agriculture will continue to play a dominant role in the country's future economic development. Consequently, improvements in the agricultural sector will have a strong bearing on the country's economic growth. Conversely, failure to stimulate meaningful growth in the agricultural sector based on judicious use of the natural resources such as land might result in declining national income, reduced savings, worsening food security, which in turn perpetuates poverty.

Table 2.1. Average annual growth rate for key economic indicators in Ethiopia, (1982-2002)

	1982-92	1992-02	2001	2002
GDP	0.7	5.5	7.7	5.0
GDP per capita	-2.4	3	5.2	2.7
Export of goods and services	-3.2	12.6	-1.6	7.7
Agriculture	1.3	2.8	11.5	4.5
Industry	-2.9	6.1	5.8	5.4
Services	1.8	8.3	4.6	5.5
Gross domestic investment	-1.8	10.3	27.4	17.4

Source: World Bank (2004)

In Ethiopia, smallholder subsistence farmers cultivating small land holdings dominate the agricultural sector. Smallholder farmers cultivate 95 per cent of the cropped area; produce more than 90 per cent of the agricultural output, and 98 per cent of the coffee. Large-scale commercial private and state farms, on the other hand, produce 6 per cent of the food and 2 per cent of the coffee (MEDaC, 1999). Cereal production accounting to about 73 per cent of the cropland and nearly 70 per cent of the caloric intake of the population dominate smallholder production, followed by pulses, oil seeds and horticultural crops (CSA, 2004). Average farm sizes vary across the country depending on population density, agro-ecology (highland vs. lowland) and production system (pastoralism vs. sedentary agriculture) but are generally very small and declining over time. For instance in 1995, of those households who have access to some type of farmland, 62.9 per cent owned less than 0.5 ha of land against 69.1 per cent in the year 2000 (CSA, 2004). Nonetheless, despite the significance of smallholder farming in the country's agriculture in terms of food production, employment and foreign exchange earnings, the attention provided to the sector until recently had been minimal. Until the late 1990's, much of the capital expenditure[1] had been targeted to the promotion of large-scale commercial farming (MEDaC, 1999).

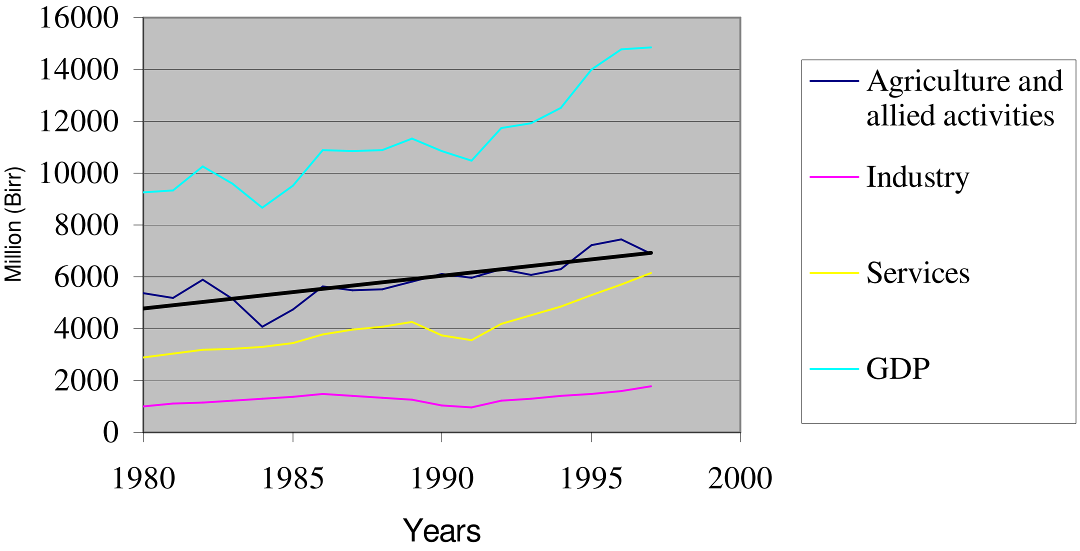

Figure 2.1. Gross Domestic Product (GDP) by sector at 1980 constant factor cost, Ethiopia, 1980-1997

Source: MEDaC (1999)

Over the years, growth in crop production by smallholder farmers has been sluggish increasing at annual average rate of 1 per cent during the 1980 to 1990 (pre-reform period) compared to 5.3 per cent in the post reform period (1991 to 1997) (Figure 2.2). These recent increases in production, however, were associated more with area expansion than yield increases. Over the last 30 years, while cereal and pulse area expanded at an average rate of 2.1per cent, cereal yields remained flat at 1.2 ton/ha (Figures 2.2 and 2.3). Area expansion has hardly been accompanied by adoption of improved farming techniques. For instance, in the years 1994 to 1998, on average, improved seeds were applied to about 2 per cent of the total area of cereals while commercial fertilizer was applied to about 38 per cent of the total area under cereals (CSA, 1999). By 1995, only

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[1] State farms and producer cooperatives, which produced less than 5 per cent of the agricultural output received more than 40 per cent of the government capital expenditure budget in the 1980's.

one third of rural households used inorganic fertilizer at the rate of 11 kg per ha (Demeke et al., 1997). Among the reasons for the low productivity of agriculture, limited use of modern inputs, lack of transportation and storage facilities, inadequate extension and credit facilities, natural calamities such as drought and ecological degradation, and poor and biased agricultural policies are most prominent (Admassie and Heidhues, 1996; Demeke et al., 1997; FAO, 1999).

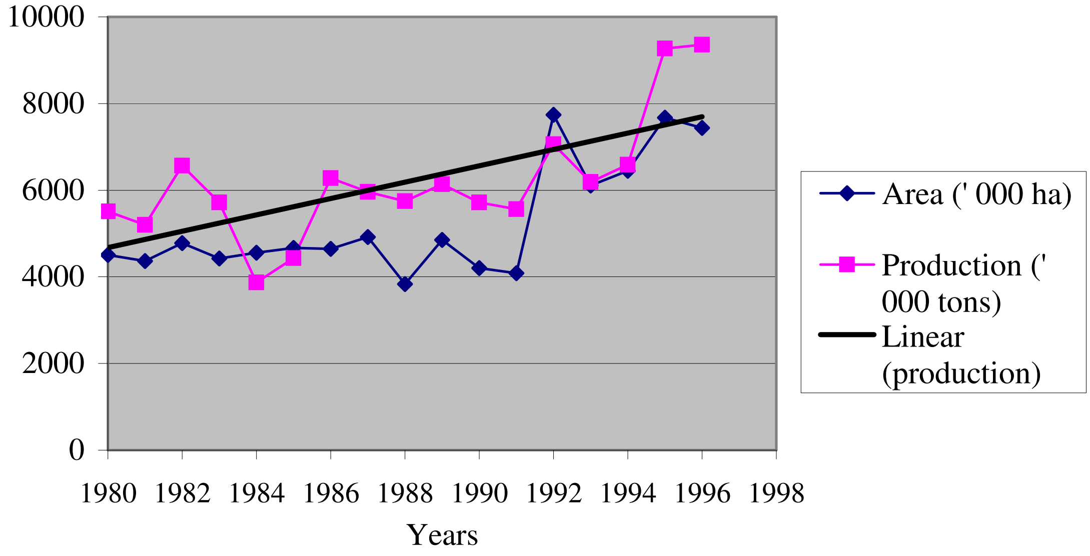

Figure 2.2. Trends in area and production of cereals in Ethiopia, 1980-1996
Source: MEDaC (1999)

At the global scale, per capita food production grew at annual rate of 0.6 per cent per annum since the 1960's (Wiebe, 1997; Shane et al., 1997). However, in SSA including Ethiopia, the last three decades have been marked by a decline in per capita food availability due to the rapid population growth relative to the growth of agricultural production (Zegeye and Habtewold, 1995; Wiebe, 1997; Shane et al., 1997; Aballu and Hassan, 1999). On the other hand, in Ethiopia for instance, population growth rate increased from about 2 per cent in the 1950's to about 2.9 per cent in the 1980's. Accordingly, the population of Ethiopia grew from 54.6 million in 1995 to 67 million in 2002 and expected to reach 120 million by 2022 (MEDaC, 1999). Consequently, per capita food production declined resulting in chronic food shortages primarily affecting the rural poor. The country with per capita income of only US $ 100 and foreign debt of more than export earnings (World Bank, 2004) lacks the means to cover domestic food production deficits through commercial imports. The deficit, however, has been largely bridged by food aid (MEDaC, 1999).

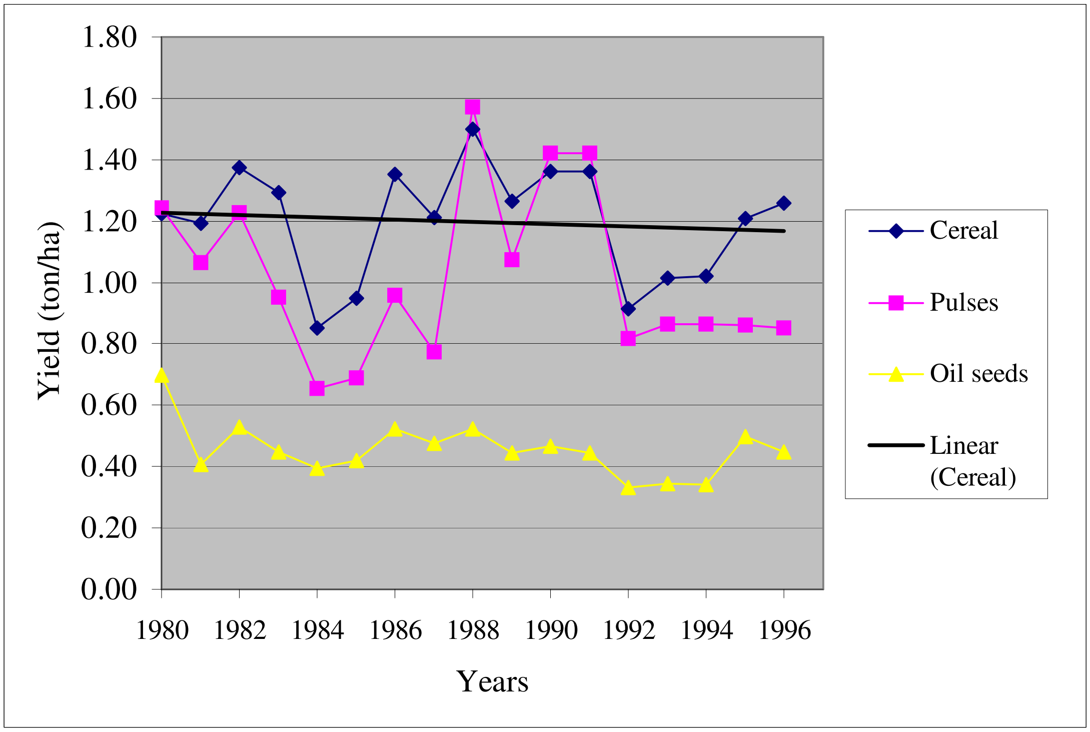

Figure 2.3. Yield trend of cereals, pulses and oil crops, Ethiopia, 1980-1996

Source: MEDaC (1999)

2.2 Overview of the soil resources and soil degradation in Ethiopia

2.2.1 Soil resources of Ethiopia

This section draws heavily on the reports of Abebe (1988) and a draft report entitled "Potentials and Research Needs for the Ethiopian Highlands" prepared by the Technical Committee for Agro-forestry (TCA) in Ethiopia submitted to the International Center for Research in Agroforestry (ICRAF) in June, 1990.

Nineteen soil types have been identified in Ethiopia, of which seven soil types namely Vertisols, Nitosols, Luvisols, Cambisols, Phaeozems, Acrisol and Lithosols make up about 88% of the soils in the highlands (Table 2.2). The importance of these soils within the highlands, however, differs from one agro-ecology to another.

In the high potential mid altitude (between 1500 and 2500 meters) zone, Nitosols and Acrisols, account for about 39.5% and 29.5 %, respectively. The relative importance of soil types is reversed in the high altitude (2,500-3,000 m) range, where Vertisols dominate followed by Luvisols.

In the low potential mid altitude (1500-2500 m) cereal zone, Cambisols and Luvisols predominate accounting for about 32% and 15%, respectively, while in the low potential high altitudes (2,500-3000 m) zone Phaeozems appear to be more important followed by Lithosols.

Vertisols are deep, black, and cracking clay soils, which expand and contract with changes in moisture content. They are low in permeability, have above average fertility and usually occur on flat to undulating topography. Their inherent texture, however, renders them less suited to many crops and often creates workability problems such as traction. In spite of their physical property, problems and their susceptibility to erosion, their nutrient retention and water-holding capacity can make them very productive (Jutzi and Mohammed-Saleem, 1992). Nitrogen and phosphorous are often the two limiting nutrients undermining the productivity of Vertisols.

Nitosols are reddish brown to red clayey soils with an accumulation of silicate clay in the B-horizon. They are dominated by kaolinitic clay and are deep with a high moisture holding capacity, physically porous, well drained and have a very good potential for agriculture. The high degree of weathering, however, induces a high capacity for P-fixation and this, coupled with the inherent low phosphorus content, makes the application of additional phosphorus a necessity for Nitosols.

Acrisols are reddish brown to red in color with argillic B-horizon and base saturation less than 50%. Physically, these soils are good because they have a well-aggregated soil structure and are porous. However, chemically they are poor due to their low pH and low available P content. They are moderately suited to agriculture and they are found associated with Dystric Nitosols.

Luvisols have distinct argillic B-horizon and a high base saturation (>50%), with varying physical characteristics such as texture, but good chemical properties. They are intensively cultivated, except in stony areas and on steep slopes, and there are permeability, workability and drainage problems in Vertic Luvisols. They have low to moderate available P content.

The characteristics of Cambisols vary because they are found under quite variable conditions. But generally, they have a B-horizon, which shows an evidence of alteration. They form under all conditions of relief (land forms); erosion and climate that are not favorable for other soil processes except weathering. These soils are predominantly found in the northern highlands.

Phaeozems have dark-colored humus-rich topsoil that contains little or no calcium carbonate. Depending on the local topography, they could be shallow, as in the northeastern escarpment, or in areas with high population density, or left for livestock grazing.

Lithosols are very shallow, young, newly weathered and weathering soils, which are extremely stony. Being less than 10 cm deep, Lithosols are too shallow for agriculture. They occur throughout the country under any one or a combination of conditions such as steep slopes, dry climate, young parent materials, or severely eroded areas.

Information on the fertility status of the Ethiopian soils is scanty. The few available evidence indicate that Potassium, Nitrogen, Cation Exchange Capacity (CEC) and organic matter contents of most Ethiopian highland soils are generally considered as high whereas their phosphorous content is low to very low (Murphy, 1963). Nevertheless, most highland soils are deficient in important nutrients and require fertilizer to sustain crop yields. For instance, Vertisols covering 10% of the geographical area of Ethiopia and about 24% of all cropped highland soils, while generally considered having above average soil fertility, nitrogen and phosphorous are the two plant growth limiting nutrients (Mamo et al., 1992). Various studies have indicated that P is a potentially limiting element for crop production in the highlands as 70 –75% of the soils of the highlands plateau region of Ethiopia are P deficient.

Table 2.2. Major types, area and distribution of soils in Ethiopia

	Dominant soil type	Area (km^2)	Area (%)	Location
1	Acrisol	55726.5	5.0	Moderate to steep slops of high rainfall areas (e.g. Western Ethiopia)
2	Andosol	13556	1.2	Northern Highlands (Western Tigray and north Gonder,), near Lake Abiyata, Lake Zway and Lake Koka
3	Arenosol	9024	0.81	On steeper slopes in the gorges of south eastern Wello at the base of Mt. Ras Dejen and in the north eastern Bale
4	Cambisol	24038	11.1	Central part of Ethiopia, north eastern escarpment, northern highlands
5	Chernozem	814	0.07	Humid temperate climate with pronounced dry seasons found on the flat pyroclastic plateau south Mt. Chilalo in Arsi
6	Fluvisols	88261.5	7.9	N.A.
7	Gleysols	5273.5	0.47	N.A.
8	Histosols	4719.5	0.42	N.A.
9	Lithosol	163185	14.7	Occur throughout the country under any one or a combination of conditions such as steep slopes, dry climate, young parent materials, or severely eroded areas
10	Luvisol	64063.5	5.8	Occur through out Ethiopia where climatic conditions are favorable for clay movement (Central Ethiopia, east and west Chercher highlands, northern highlands, parts of southern Sidamo, southern Rift Valley in the coarser textured granitic soils, further south of flood plain of Awash river)
11	Nitosols	150089.5	13.5	In the central highlands and the western lowlands, where Chercher highlands are wettest, north of Lake Tana, southern Rift Valley (moving upward out of the Rift)
12	Phaeozem	32551	2.9	Widely spread on the northeastern escarpment and northern highlands (western Tigray, northern Gonder, Wello), Central (Blue Nile Gorge) and Chercher highlands
13	Regosol	133596	12.0	Northern Wello, eastern Tigray, on sand stone plains of eastern Ogaden on flatter land forms where volcanic ash deposits are found occasionally on largely windblown slope debris materials on the flatter land forms

	Dominant soil type	Area (km^2)	Area (%)	Location
				throughout Danakil and in the eastern Danakil
14	Rendzina	16348	1.5	Moderate to steep side slope of limestone landforms in the central, northern and Chercher highlands
15	Solonchak	47217.5	4.2	Found in arid areas on colluvial slopes on evaporite deposits (Ogaden), Awash river valley, around Lake Shala, Danakil and in the extreme southern Rift Valley in the areas of Chew Bahir
16	Solonetz	495	0.04	N.A.
17	Vertisol	116785	10.5	Flat to undulating land throughout Ethiopia where fine textured colluvium collects except in the very driest areas and when the parent material is evaporite on flood plains of major rivers where fine textured alluvium has concentrated largest extents found in central Ethiopia in basins with seasonal drainage deficiencies
18	Xerosol	53171	4.8	Extensive in the semi-arid areas of Ethiopia
19	Yermosol	34950	3.1	On vast plains of the arid and semi-arid regions of Ethiopia (Ogaden) more representative for arid regions

N.A.= Information not available

Source: Adapted from Abebe (1988) and Mengistu (2003)

2.2.2 Soil degradation in the Ethiopian Highlands

Soil is a fundamental input in agriculture. Inappropriate uses of soil resources have been a concern at the global, regional and national level for the mere fact that agricultural production may not be sustainable with diminishing soil quality (Pagiola, 1999; Aballu and Hassan, 1999; FOA, 1999; Wiebe, 2003). In the Ethiopian highlands, though, all forms of soil degradation exist; excessive soil losses due to water erosion and nutrient depletion stand to be the most important (Bojo and Cassels, 1995; FAO, 1999; Elias, 2002; Zeleke, 2003).

Various authors indicated that data on land and soil degradation worldwide is extremely limited, incomplete and often unreliable (Pagiola, 1999; FOA, 1999; Wiebe, 2003). Likewise, in Ethiopia, soil degradation related data are scanty, poor in quality, mostly qualitative and at best highly location-specific posing difficulty in extrapolation of results to a wider scale (Kapple, 1996). Available data indicate that out of the 60 million hectares of agriculturally productive land, about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded, and 7 million hectares are considered no more agriculturally productive (Abebe, 1990 cited in FAO, 1999).

In the highlands of Ethiopia erratic rainfall causing high surface runoff contribute to sheet and rill erosion (SCRP, 1996). Reported water erosion induced soil loss rates in the highlands varied considerably from one location to another depending on climatic conditions, soil type, land use, etc. According to FAO (1986), annual soil loss induced by soil erosion from arable lands in the Ethiopian highlands averaged 100 tons/ha with a mean productivity loss of 1.8 per cent per annum. Similarly, Hurni (1993) based on empirical studies from the Soil Conservation Research Project (SCRP) estimated the annual soil loss from croplands at 42 tons/ha. Other studies, Sutcliffe (1993) and Bojo and Cassels (1995) reported annual soil loss of 45 tons/ha and 20 tons/ha, respectively, with average productivity loss of 0.21 per cent per annum. Furthermore, losses of soil nutrients along with removed soil are staggering, about 36-429 kg/ha/year for total N, 0.412-5 kg/ha/year for available P and 1.4-17 kg/ha/year for exchangeable K (Table 2.3).

Kappel (1996) noted that this variability in estimated soil loss and its associated productivity loss rates might be attributed to the complex nature of land degradation, difficulty in measurements and uncertainty with extrapolation.

Table 2.3. Calculated range of nutrient losses removed along with water erosion induced soil loss from the highlands of Ethiopia

Plant Nutrient	Nutrient content of soil	Soil loss range (ton/ha/year)		Total amount of nutrient lost (kg/ha/year)	
		Lowest	Highest	Lowest	Highest
Organic matter (per cent)	2.0	18.0	214.4	360	4,288
Total N (per cent)	0.2	18.0	214.4	36	429
Available P (ppm)	22.9	18.0	214.4	0.412	5
Exchangeable K (per cent)	0.0078	18.0	214.4	1.40	17
Exchangeable Ca (per cent)	0.16	18.0	214.4	28.8	343
Exchangeable Mg (per cent)	0.048	18.0	214.4	8.64	103

ppm=parts per million

Source: FAO (1999)

Furthermore, Sanchez (2000) indicated that soil fertility exhaustion is the root cause of declining food production in smallholder farms of tropical Africa with fertility depletion rates 7 times larger than annual fertilizer imports. He noted that 37 African countries had lost 132 million tons of N, 15 million tons of P and 90 million tons of K from their cultivated lands during the last 30 years. In the highlands of Ethiopia, continuous mono cropping of cereals, reduced or total abandonment of fallowing, none or minimal nutrient inputs has also contributed to the negative soil nutrient balances (Tanner et al., 1992; Yirga and Hassena, 2001). For instance, wheat and barley, the two most widely grown crops in the highlands, remove 40-56 kg/ha of N, 7.8-12.3 kg/ha of P and 12.3-16.8 kg/ha of K in the grain and 16.8-33.6 kg/ha of N, 2.4-3.9 kg/ha of P and 56-67.2 kg/ha of K in its straw (Table 2.4).

Noteworthy, in Ethiopia, the high natural forests that once covered about 35-40 per cent of the country's land has largely been converted into cultivated lands. Currently, the forest cover is estimated at about 2 per cent. Obviously, the widening gap between agricultural productivity and population growth rate has resulted in major land use conflicts between arable farming, animal grazing and forestry in the highlands (Kidanu, 2003). Federal government efforts to rehabilitate degraded land, maintain and expand national parks, natural forest reserves and plantations are in sharp conflict with local people interest to clear up the areas for cultivation or grazing. Regional state and community forest interests on land enclosed for rehabilitation collide with local grazing interests. Needs of individual households for immediate grazing and fuel wood collide with community interest for woodland. The fact that there exists a conflict on land use between individual households (to expand arable farming and livestock grazing thus degrade the land) and the government (conserve land) as a custodian of public interests suggest the existence of a divergence between private and social objectives concerning the optimal level of land degradation.

Table 2.4. Mean nutrient removals (N, P, K_2O_5) of some cereals in the Eastern highlands of Alemaya, Ethiopia

Crop	Yield (kg/ha		Nutrient removals (kg/ha)		
			N	P	K
Maize	Grain	4072	100.8	17.2	28.0
	Stalk	-	78.4	12.3	106.4
Sorghum	Grain	3263	56.0	12.3	16.8
	Stalk	-	72.8	9.8	106.4
Wheat	Grain	2688	56.0	12.3	16.8
	Straw	-	33.6	3.9	56.0
Barley	Grain	2240	40.0	7.8	12.3
	Straw	-	16.8	2.4	67.2

Source: Hawando (1989) cited by Elies (2002)

Therefore, given, the expansion of cultivated lands into marginal and hillsides, continuous cropping, the high proportion of cereals in the cropping system, the use of animal manure for domestic fuel and inadequate replenishment of removed nutrients through crop harvest and organic matter, soil degradation is likely to worsen in Ethiopia.

2.2.3 Impact of soil degradation

Various studies have shown that the impacts of soil degradation have far-reaching consequences for low-income countries such as Ethiopia. Land degradation results in loss of current as well as future income, increased risk of crop failure and more importantly affects the most vulnerable group of society, the poor. While empirical research on the impact of soil degradation in the developed world emphasized off-site costs of soil degradation, studies in low-income countries focused on on-site costs that have a direct bearing on sustainability of agriculture in low-income countries reflecting the relative priorities placed on the soil degradation problem in the respective parts of the world (Barbier, 1995). In spite of the high profile placed on the problem of soil degradation in low-income countries, empirical studies estimating impact of soil degradation are few in SSA. The few studies in SSA estimated the national economic loss to be substantial, for Ethiopia ranging from 2 to 6.7 per cent of agricultural gross domestic product (Bojo and Cassels, 1995; Kappel, 1996). However, Kapple (1996) noted that available studies are severely affected by methodological problems primarily arising from the difficulty of deriving average regional or national level soil loss rates; disagreement on the net erosion rates as a result of difficulties encountered in estimating redeposition rates; lack of knowledge on land use pattern at a national or regional level; and the difficulty of establishing and quantifying definitive relationships between net soil loss and yield loss.

Other studies also estimated the opportunity cost of using livestock dung and crop residues as domestic fuel in the Ethiopian highlands in terms of lost production could be as high as 700, 000 tons of grain equivalent (Bojo and Cassels, 1995).

It is clear from the above that soil degradation in SSA in general and in Ethiopia in particular is a crucial natural resource problem affecting productivity and food security in the region. Available estimates of the impact of soil degradation are useful to the extent that they indicate the magnitude of the problem but could not provide the full costs that continued soil degradation will have on the country's economic development. Kappel (1996) noted that the few empirical studies available in SSA including Ethiopia are based on static models, which probably result in rather conservative estimates of ecological and economic damage. He further emphasized the need for studies that take into account the dynamic forces deriving soil degradation in SSA employing more rigorous approaches.

2.2.4 Soil conservation and soil fertility management efforts in Ethiopia

In response to the problem of soil degradation, considerable resources have been devoted to understand the physical processes involved in soil degradation, develop technical solutions in the form of improved technologies, adapt the technologies on farmers' fields and disseminate available technologies to smallholder farmers for widespread use. Among the most notable are the crop response trials to various levels of inorganic fertilizers (N, P, K), liming, crop rotations (Tanner et al., 1999; FAO, 1999); drainage methods to draw off excess runoff from croplands (Jutzi and Mohammed-Saleem, 1992, Erkossa et al., 1999); studies to understand the technical relationship between soil conservation methods, runoff and soil loss rate; and design soil conservation structures that stabilize and reduce soil loss (SCRP, 1996). Among the improved soil conservation practices, terraces, soil-stone bunds, check-dams and live barriers have been widely promoted by various projects and programs to control soil erosion. Inorganic fertilizers and crop rotations involving leguminous crops have also been extensively promoted to enhance soil fertility thereby reduce soil mining.

2.2.4.1 Soil conservation research and extension efforts in Ethiopia

In Ethiopia, soil conservation is as old as agriculture itself. Smallholder farmers in various parts of the highlands have been using a variety of soil conservation and soil fertility management practices with various intensities (Kruger, et al., 1996; Gebre Micheal, 1999; Regassa, 2001). However, over the years, the importance of traditional soil conservation practices except in few isolated places such as Konso in Southern Ethiopia and Ankober in North Shewa have declined owing to demographic pressures, socio-economic and institutional dynamics that took place over the last three decades.

Nonetheless, a considerable effort had been made to generate, adapt and disseminate a variety of soil conservation practices across the highlands since the 1970's. Most notable are the soil and water conservation (SWC) extension program initiated and implemented with the assistance of the World Food Program under the food-for-work project and the Soil Conservation Research Project (SCRP) initiated in 1981 in collaboration with the Institute of Geography of the University of Berne, Switzerland. The SCRP with its 7 sites[3] scattered throughout the highlands was charged with providing the necessary basic data for the proper implementation of the soil conservation program already underway; conduct basic research on soil erosion; develop soil and water conservation measures appropriate for the various agro-ecologies of the highlands; and train local personnel in this field of study (SCRP, 1996). The SCRP had developed a number of soil conservation techniques and generated a wealth of data, which has helped initiate several studies on various aspects of soil degradation in Ethiopia (SCRP, 1996; Gebre Micheal, 1999; Kapple, 1996; Shiferaw and Holden, 2001).

The achievements of the SWC program, which was implemented with the assistance of the World Food Program (WFP), were immense. Between 1980 to 1994, about 1, 045,130 ha of land were treated with soil bunds and hillside terraces, 17, 880 km check dams and cut-off drains were constructed; 1, 259, 760 ha were covered by closure and aforestation; and about 170 small earth dams were constructed (Gebre Michael, 1999).

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[3] One of the sites is located in Eritrea

The achievements of the program, however, were short lived. Following the government change in 1991 and subsequent introduction of policy reforms in 1992, most of the conservation structures were either dismantled or not maintained; community forests were cut down; and enclosed hillsides for rehabilitation were opened for communal grazing (Shiferaw and Holden, 1998; Gebre Michael, 1999; Kapple, 1996; Zeleke, 2003). The most outstanding reasons often mentioned behind the failure of the intervention were:

- Top down approach which did not involve the cultivators of the land
- Over emphasis on structural measures for erosion control
- Uniform application of measures regardless of variations in agro ecological conditions and land forms
- Over dependence on food-for-work programs to carry out soil conservation structures
- Lack of a clear policy, especially concerning ownership, control and utilization of afforested areas and closed hillsides

Another major drawback of past soil conservation efforts in Ethiopia have been overemphasis of ecological effectiveness and technical simplicity as a guiding principle in the design of soil conservation practices giving little attention to profitability and economic incentives such as cost effectiveness (Kapple, 1996; Shiferaw and Holden, 2001; Okumu, et al., 2003).

2.2.4.2 Commercial fertilizer use in Ethiopia

In Ethiopia, increased use of inorganic fertilizers is considered key to reducing poverty and feeding the ever-increasing population. Consequently, a considerable effort has been placed on promoting the use of fertilizer through a combination of programmes including fertilizer trials, demonstrations and special projects.

Commercial fertilizer was introduced in Ethiopia in the 1950’s with the establishment of private large commercial farms. In subsequent years, the Extension Program introduced commercial fertilizer to smallholder farmers. However, its use among smallholder farmers have become popular only after the FAO's fertilizer program known as the Freedom from Hunger Campaign (FFHC) launched in 1967. Subsequent introduction of commercial fertilizers to smallholder farmers on a large-scale basis became successful as a result of the establishment of the Minimum Package Program (MPPs) under the Extension and Project Implementation Department (EPID) of the Ministry of Agriculture (MOA) in the 1970's. The use of commercial fertilizer further became popular with the establishment of the integrated agricultural development programs popularly known as Chilalo Agricultural Development Unit (CADU) later known as the Arsi Rural Development Unit (ARDU) in the former Arsi province, the Wolayta Agricultural Development Unit (WADU) in Southern Ethiopia and the Ada District Development Program (ADDP) in the Debre Ziet area. More recently the Sasakwa 2000 Project and the Participatory Demonstration and Training Extension System (PADETES) run by MOA have also been actively involved in the dissemination of commercial fertilizers along with improved crop seeds. Thus, farmers in the highlands of Ethiopia have known and used inorganic fertilizers for over 30 years.

However, commercial fertilizer consumption in Ethiopia remained low until 1992 primarily due to supply constraints but showed remarkable increase with improved availability associated with policy reforms. Consumption increased from 190,000 ton in 1994 to 253, 000 ton in 1996 and 286, 000 ton in 1999 (Figure 2.4). For Ethiopia as a whole, the proportion of farmers using commercial fertilizers was estimated to be less than 7 per cent in 1982 (FAO, 1988); increased to 15 per cent in 1992 (Makken, 1993); and reached 31 per cent in 1997 (Demeke et al., 1997). Likewise, intensity of use measured as kg of nutrients per hectare of cultivated land grew from less than 7 kg in 1992 (Makken, 1993) to 17-20 kg in 1999 (Adunga and Demeke, 2000). Although, both the number of households and intensity of use of commercial fertilizers by smallholder farmers in Ethiopia have shown modest growth particularly after market liberalization, it still stands out as one of the lowest in Africa. The comparable figure for the year 1995 is 10 kg/ha in SSA, 65 kg/ha in Latin America, 77 kg/ha in South Asia and 216 kg/ha in East Asia (Yanggen et al., 1998).

Much worse is the low use of organic forms of fertilizer such as compost. This is mainly because much of the dung and crop residues are increasingly utilized as sources of energy for domestic use (Makken, 1993; Bojo and Cassels, 1995; Elias, 2002). Agricultural technology adoption studies conducted in various parts of the country prior to market liberalization showed that knowledge of the benefits of using fertilizer and other inputs is widespread but limited supply and late delivery of fertilizer and improved seeds hindered increased fertilizer use (Waktola, 1980; Kebede, 1990; Yirga et al., 1996; Croppenstedt and Demeke, 1996; Alene et al., 2000; Croppenstedt et al., 2003). Therefore, given the low use of inorganic fertilizers, continued use of livestock dung and crop residues as domestic fuel, high proportion of cereals in the cropping system and unabated soil erosion implies soil nutrient mining will continue to be a major challenge in the foreseeable future in the highlands of Ethiopia.

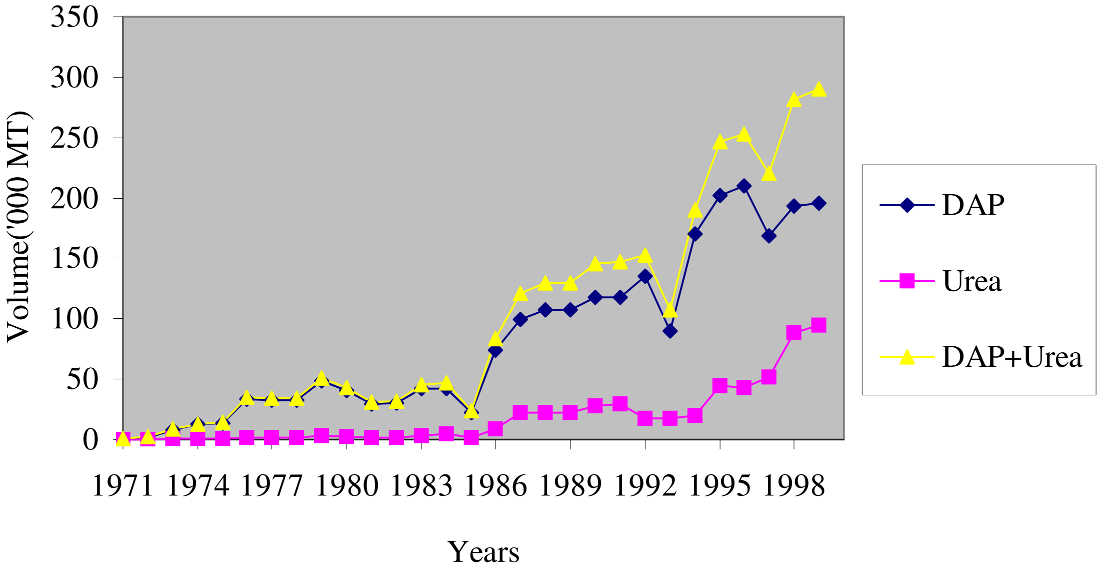

Figure 2.4. Commercial fertilizer use in Ethiopia, 1971-1999

Source: Adugna and Demeke (2000)

2.3 The policy environment

In Ethiopia, apart from the recurring drought, which has severely disrupted food production, agricultural development policies have often been blamed for the unsustainable use of natural resources (Stroud and Mekuria, 1992; Makken, 1993; Demeke et al., 1997; FAO, 1999; Adunga and Demeke, 2000). Among the economic policies of past governments that either denied enabling environment or hindered agricultural productivity include urban biased economic development policies; exploitative land tenure relationship that prevailed during the imperial government; agricultural development policies of the socialist government which were characterized by heavy control (Stroud and Mekuria, 1992; Adal, 2000; Adunga and Demeke, 2000; Haile Gabriel, 2003; Adal, 2003; Rahmato, 2004).

2.3.1 Agricultural development policy

The economic development strategies of Ethiopia in the 1970's and 1980's were largely biased against smallholder farming. The two successive Five Year Plans (1957-61 and 1962-67) emphasized industrialization and large-scale commercial farms that could produce commodities either for export or effectively substitute imports (MFD, 1957; MFD, 1962). It is only in the third Five Year Plan (1968-1973) that smallholder farming received attention. Even then, it was assumed that substantial agricultural improvements would be gained through promoting improved packages of agricultural technologies by concentrating efforts on few selected high potential areas. As a result, the vast majority of smallholder farmers producing for subsistence using traditional farming techniques on less favored areas with visible symptoms of soil degradation were neglected. Much worse, the economic development policy of the military regime which were characterized by state ownership of land, nationalization of industries, collectivizing commercial private farms, government control of agricultural input and output markets, forced food grain deliveries at fixed prices and involuntary villagization of farm households by denying favorable economic environment and the private incentives required for sustainable use of natural resources contributed to natural resource degradation (Stroud and Mekuria, 1992; Demeke et al., 1997; MEDaC, 1999; Gelan, 2002) .

The Transitional Government of Ethiopia (TGE), which replaced the socialist regime in 1991, subsequently renamed as the Federal Democratic Republic of Ethiopia (FDRE) adopted an Economic Reform Program in 1992. The economic reform program aimed at stabilization and trade liberalization to revive the economy that had suffered from many years of civil war, food security crises and heavy control (MEDaC, 1999; Gelan, 2002). The most important measures taken under this reform program include: devaluation of the local currency, disbanding of producer cooperatives, drastic reduction of subsidies to state farms, elimination of compulsory food grain quotas and liberalizing input markets (MEDaC, 1999; Gelan, 2002). These policy reforms have been further strengthened through the adoption of a new development strategy popularly known as "Agricultural Development Led Industrialization (ADLI)".

ADLI, primarily focusing on the agricultural sector, aimed at bringing about productivity improvements to the smallholder agriculture and expansion of private commercial farming. Improvements in the agricultural sector was hoped to provide commodities for exports, satisfy domestic food requirements and supply industrial inputs. Improvements in the agricultural sector in turn were expected to help expand market for domestic manufacturing as a result of increased income of smallholders. Establishing an effective input delivery and marketing system which can ensure adequate and sustained agricultural inputs such as fertilizers, improved seeds and crop protection chemicals to smallholder farmers in the required quantity, product mix, at the right time and at a reasonable price is considered key to the success of the development program (Demeke et al., 1997; MEDaC, 1999; Haile Gabriel, 2003; Bayu, 2003).

Furthermore, the current government has adopted a number of strategies and policies including a food security strategy, a poverty reduction strategy, natural resources conservation policy, resettlement policy, health policy focusing on disease prevention and a policy of free primary education aimed at reducing poverty, improve food security, develop skilled and healthy work force thereby bring a tangible improvement in the welfare of the population (Haile Gabriel, 2003; Bayu, 2003; Rahmato, 2004).

2.3.2 Land tenure regimes

Land tenure represents the social relations and institutions governing access to and ownership of land and natural resources (Maxwell and Wiebe, 1998). Land tenure through the rights and obligations it bestows on farm households thus determines both short and long-term investment decisions and the benefits landholders derive there off.

As in most parts of Africa, land tenure in Ethiopia has been the subject of debate among farmers, policy makers, researchers and the public at large. Historically, in Ethiopia, land was viewed not only as a source of livelihood to the majority of the population but also a source of political and economic power to all groups who aspire to hold political power (Adal, 2000; Adal, 2003; Rahmato, 2004). Consequently, the land tenure reforms that Ethiopia witnessed had been designed and implemented in the light of the political advantages it was presumed to yield to successive governments with very little economic rationale.

Prior to the 1974 land reform, land tenure in Ethiopia was characterized by a complex system of ownership namely communal, church ownership, private and state holdings (Rahmato, 1984; Adal, 2003). State or government holdings were most prevalent in the less densely and pastoral areas of the lowlands irrespective of geographical location. While communal ownership locally referred as “Rist” and church holdings characterized the northern highlands including Gojam, Gonder, Tigray and parts of Wollo, private holdings were a feature of the South.

The communal system (Rist) was based on the principle that land is the collective property of the community that bestows access and transfer rights to its individual members who can trace his/her kinship ties to the founding ancestors. However, land could not be sold or mortgaged. The presence of a descent system that allows an individual to be a member of different kinship groups at the same time, often arising from intermarriages, entitles the individual to claim land from several kinship groups irrespective of residence of the individual or geographical locations of the contested land. Consequently, farmers end up in endless land related litigations which claimed valuable time and resources, led to land fragmentation and in certain cases to absentee landlordism (Regassa, 2001).

In the south, private ownership of land was developed as a result of land grants by the government to loyalists of the imperial regime. As a result, land was concentrated on the hands of few individuals, which subjected the cultivators of the land to treats of arbitrary eviction and exploitative landlord-tenant relationship. Consequently, the land tenure system during the imperial regime did not provide enough incentives to the cultivators to manage land in a more sustainable manner.

Following the 1974 land reform, the government nationalized all rural land, ended all forms of tenancy, and distributed land to farm households based on family size (Stroud and Mekuria, 1992; Rahmato, 1984; Adal, 2000; Teklu and Lemi, 2004). However, farmers had only restricted usufruct rights but were not allowed to transfer their holdings in any form (inheritance, renting, share-cropping or gift). Land was re-distributed frequently in order to reduce landlessness as well as to address land quality differences until 1991. Smallholder farmers were also evicted from their holdings to give way for state farms and producer cooperatives. Various studies indicated that the land tenure policy of the military governments has resulted in diminution of size of land holdings and tenure insecurity with all its adverse effects of unsustainable utilization of natural resources (Rahmato, 1994; Adal, 2000).

Following the fall of the socialist regime in 1991, the new government introduced a series of political and economic reforms. It allowed land leasing and inheritance subject to some restrictions. Nonetheless, land remained to be the collective property of all nations, nationalities and peoples of Ethiopia under the custody of the government. The constitution entrusted regional governments to implement their own land laws. Land distribution in the Tigray region was implemented in 1990 before the rural land act was passed; in the Amhara region in 1997 and 1998 whereas other regions have not yet implemented any land distribution since the fall of the socialist government (Adal, 2000; Adal, 2003; Rahmato, 2004; Teklu and Lemi, 2004).

Essentially, the land tenure of current Ethiopia appears to be similar to what prevailed during the socialist regime. Insecure land tenure among others has continued to be one of the most important factors responsible for the slow progress of improvement in agricultural productivity and the dire condition of natural resources in the country.

2.3.3 Agricultural pricing policies

Economic theory suggests that government initiatives influence the use of agricultural inputs and consequently the relative desirability of farming practices through the provision of structures of incentives and institutional arrangements. An important policy tool pursued by governments in SSA, until recently, had been input and output price controls via parastatals which dominated the agricultural sectors from procurement to retail distribution (Franzel et al., 1992; Makken, 1993; Demeke et al., 1997; Adunga and Demeke, 2000). This has resulted in system inefficiency, limited supply attributed to shortage of hard currency and late delivery (Makken, 1993; Adunga and Demeke, 2000).

In Ethiopia, the Agricultural Input Supply Corporation (AISCO), a government parastatal, had dominated the agricultural input (fertilizer, pesticides and improved seeds) procurement and distribution until recently (Franzel et al., 1992; Makken, 1993; Adunga and Demeke, 2000). Like in most other African countries, the agricultural input market had been liberalized in Ethiopia to do away with these structural inefficiencies. The government adopted a gradual approach of: (1) easing legal restrictions on the issuing of fertilizer licences to private individuals and companies; (2) increasing the involvement of the private sector in the distribution and selling of fertilizer and agro-chemicals as well as in the production and marketing of improved crop seeds; and (3) deregulation of prices in order to establish an effective input delivery and marketing network. Farmers have also been encouraged to use improved agricultural technologies consisting of improved seeds, recommended fertilizer and weed control practices through a popular extension package since 1996. However, an important debate is currently under way among the various stakeholders (policy makers, farmer representatives, researchers and development workers) concerning the relative merits of the market liberalization as input prices has risen much more rapidly than output prices (Adunga and Demeke, 2000; Adal, 2003).

Figure 5.2 shows crop and fertilizer prices[4] for the years 1987-1997 for Ethiopia. Over the years, for which data are available, both fertilizer (DAP and Urea) and output (teff, wheat, barley and faba bean) prices have shown a steady upward movement.

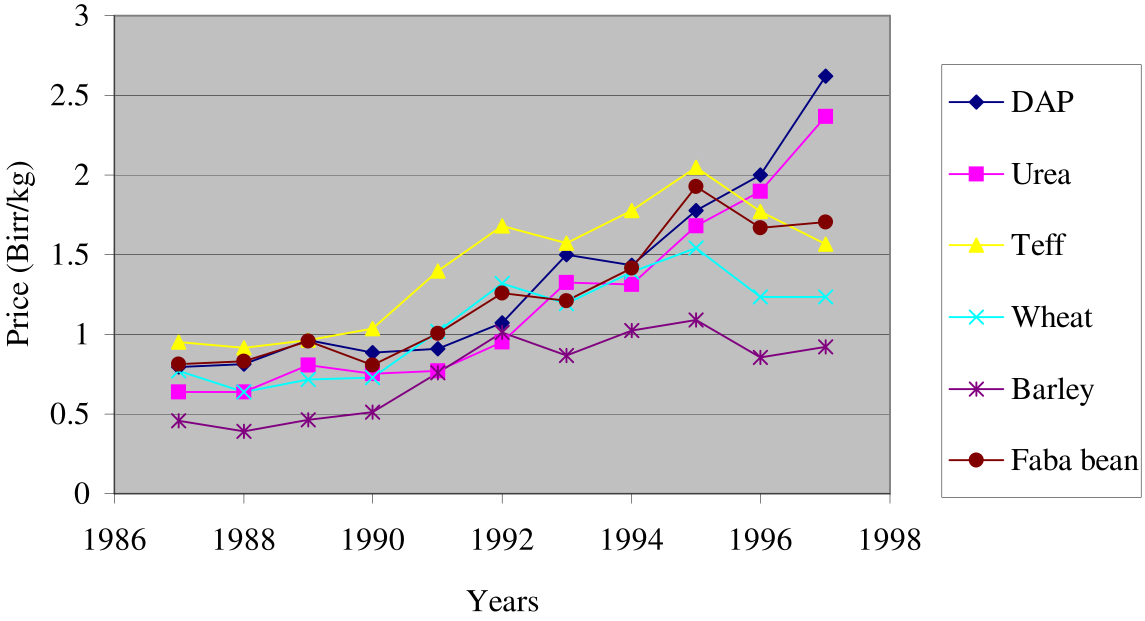

Figure 2.5. Price trends of commercial fertilizers and major crops in Ethiopia, 1987-1997
Source: MEDaC (1999), HARC (unpublished)

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[4] DAP and Urea fertilizers prices pertain to wholesalers in Addis Ababa which in effect are much lower than what farmers are expected to pay at distribution points while the crop prices refer to actual prices received by farmers at a local market at Holetta some 45 km from Addis Ababa collected by Holetta Agricultural Research Center (HARC)

However, the price of fertilizer (DAP) has risen much faster than crop prices suggesting farmers terms of trade has worsened over the years (Figure 2.6)

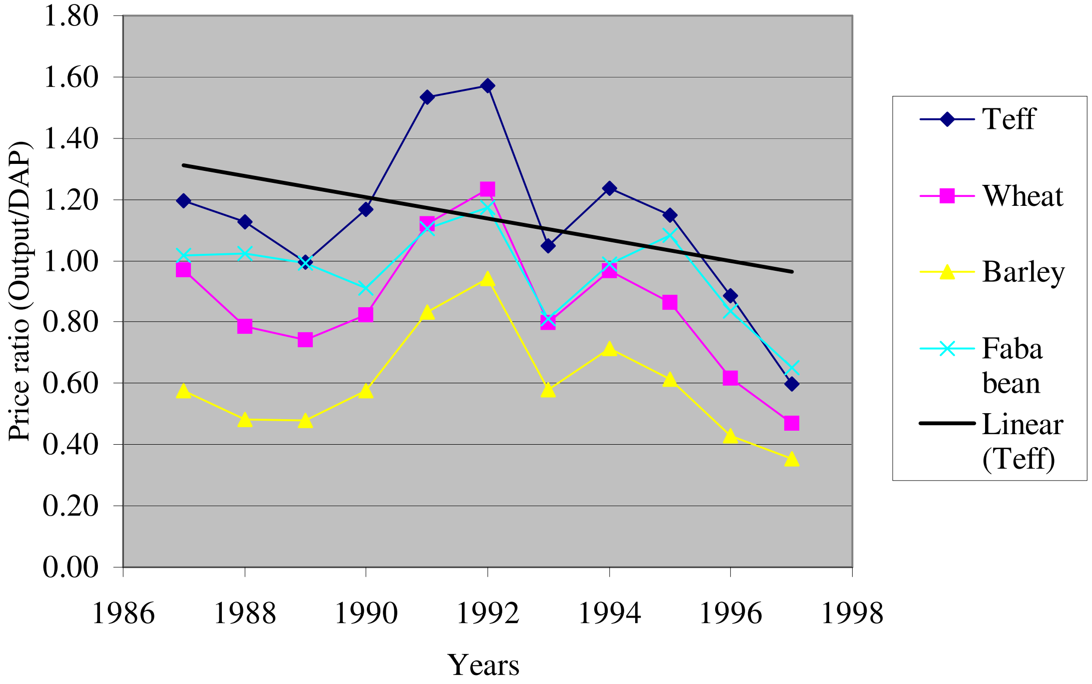

Figure 2.6. Trends in output to DAP price ratio in Ethiopia, 1987-1997

Source: MEDaC (1999), HARC (unpublished)

2.4 Summary

Over the last three decades, agricultural production and income growth in Ethiopia lagged behind population growth. Thus, per capita food production, income and savings have been falling. Disturbingly, in the highlands, soil, the basic natural resource on which the livelihood of the majority of the population is based has been progressively degraded due to a combination of biophysical, demographic and socio-economic factors. Excessive soil loss rates reaching over 100 tons/ha on croplands are not uncommon. Much worse, the amount of nutrients extracted from the soil through cropping is estimated to be several folds the nutrient inputs added to the soil in the form of organic and inorganic nutrients. As a result, crop yields have declined, at best stagnated and the number of food insecure people in the country has risen.

Past efforts to increase agricultural productivity, improve farm income, contain soil erosion and reverse soil nutrient mining have been severely hampered by inappropriate agricultural policies. Farmer incentives to invest in soil conservation and soil fertility enhancement practices have been constrained by a combination of the biophysical environment, population pressure, the institutional set up and farmer objectives. First, the institutional set-up by denying smallholder farmers secured land tenure hampered private investments in soil conservation and soil fertility enhancement. Second, the presumption that the country's food problem could be addressed through a quick fix of technological solutions prompted government and donor agencies alike to adopt a technology transfer approach focusing on short-term programs in high potential areas such as the development and transfer of improved crop technologies (improved crop varieties, commercial fertilizers, pest control measures) and public investments in simple physical soil conservation structures (soil and stone bunds) that supposedly provide quick returns at the expense of programs that have a long-term nature. Third, the high population pressure characterizing the highlands of Ethiopia led to land fragmentation as the available land have been redistributed to the increasing population over generations. Land fragmentation coupled with lack of suitable technologies to intensify farming forced farmers to either expand farming into marginal areas and/or mine the soil using traditional technologies that once were sustainable under low population pressure. Fourth, smallholder farmers primarily concerned with securing adequate food for their family immediate needs employ low-external input and erosive farming techniques which do not only mine the soil but also jeopardize the nations long-term food production ability.

CHAPTER III: REVIEW OF ANALYTICAL AND EMPIRICAL APPROCHES TO STUDYING SOIL DEGRADATION AND CONSERVATION

This chapter reviews the relevant literature on the economics of soil degradation control. The first section defines the concepts of soil capital, soil quality, soil degradation and explores the link between soil quality and soil erosion as well as soil quality and soil nutrient depletion. The section also reviews the traditional measures of soil quality and models used to estimate and predict the rate of soil erosion. Section two explores the causes for the divergence between the private and social optimal rates of soil depletion. Section three summarizes the links between soil degradation and soil productivity, which forms a prerequisite for economic analysis of soil degradation. Section four has two parts. While part one reviews the approaches often used by economists to measure and model economic costs and benefits of soil use and conservation, part two focuses on behavioral models used to analyze the adoption decision and the factors constraining smallholder farmers from adopting soil conservation and soil nutrient management practices.

3.1 The relationship between soil quality and soil degradation processes

3.1.1 The soil capital

Capital could be classified into four general categories: natural, manufactured, human and social. Natural capital is the stock of environmentally provided assets such as the atmosphere, soil, water, fish and wetlands (Sanchez et al., 1997). Soil is thus a natural capital that provides long-term economic, production and environmental service flows to society. Soil has three fundamental functions (Larson and Pierce, 1994). First, it provides the physical, chemical and biological processes indispensable for plant growth. Second, it stores, regulates and partition water flow through the environment. Third, it buffers environmental change through the assimilation of wastes. While the first function relates to agricultural production, the second and third functions relates to maintaining environmental quality through the protection of water and air quality, which in turn also affects agricultural production. The capacity of a nation's soil resources to properly function and provide a sustained flow of productive and supporting services, however, depends on maintaining and enhancing the quality of the soil capital.

Soil quality is defined as the capacity of soil to perform specific functions in relation to human needs or purposes including maintaining environmental quality and sustaining plant and animal production (Lal, 1993, 1994). Soil quality derives from a variety of particular physical, chemical, and biological properties that support these functions, including top soil depth, texture, bulk density, and water holding capacity; organic matter, pH level, and extractable nitrogen, phosphorous, and potassium; and microbial biomass. Improved soil quality can increase farm productivity, minimize the use of external inputs, improve water and air quality, and help sequester greenhouse gases (Pagiola, 1999; FOA, 1999). However, both natural processes and agricultural production can reduce soil quality and hence impair its contribution to long-term productivity and environmental quality (Lal, 1993, Lal, 1995).

3.1.2 Soil erosion and soil quality

Soil erosion is a three-step process involving detachment (or entrainment) of particles from the soil surface, down current or down wind movement of the detached particles, and deposition of the transported particles. Erosion by removing topsoil and depositing elsewhere results in a general decline in soil quality because of changes in physical, chemical and biological properties such as top soil depth, soil organic carbon content, nutrient status, soil texture and structure, water holding capacity, and water transmission characteristics that ultimately reduce crop quality and yield (Lal, 1993; Lal, 1995). On the other hand, soil mining (soil depletion or decline of soil fertility) occurs when soil nutrient extraction due to cropping exceeds soil nutrient inputs (Stoorvogel and Smaling, 1990; Ofori, 1995). Soil degradation could therefore be viewed as a decline of soil quality resulting from the twin forces of soil erosion and nutrient mining working on the physical, chemical and biological properties of soils. Lal (1988) defined soil degradation as the temporary or permanent lowering of the productive capacity of land. Soil degradation could be manifested in several forms including water erosion, wind erosion, biological degradation (decrease in humus), physical degradation (increase in bulk density, decrease in permeability), chemical degradation (acidification, toxicity) and excess of salts (salinization, alkalinization) (Lal, 1995; FOA, 1999). In SSA, soil erosion and declining soil fertility together constitute a major threat to agricultural development and sustainable natural resource management (Ofori, 1995; Brekke et al., 1999).

Natural resource capital is normally categorized as renewable and non-renewable depending on the time scale during which reproduction occurs. LaFrance (1992) considers soil as a renewable resource that is generated naturally at a slow but autonomous rate while Barbier (1995) considers it as a semi-renewable resource due to the fact that soil accretes at an extremely slow rate. Brekke et al. (1999) based on the nature of degradation suggested that when the major reason for land degradation is nutrient loss, soil resources could be safely considered as renewable natural resources since soil quality can be improved through the addition of organic and inorganic fertilizers that enables the soil resources to provide a sustained flow of services. On the other hand, if the source of degradation is from loss of topsoil and physical structures, soil resources could best be identified as slowly renewable as these damages are irreversible over a reasonable period of time. Similarly, Barbier (1995) indicated that soil in agriculture is usually treated as a potentially depletable resource due to the fact that most farming activities result in rates of erosion that exceeds the natural rate of soil erosion that would occur in the absence of cultivation practices. Knowledge of soil quality, the conditions under which it regenerates or degrades and their interaction with management is thus important in designing management practices and policies that could contribute to the sustainable use of soil resources. The two most important processes that adversely affect soil quality and hence contribute to soil degradation in Ethiopia are soil erosion and soil nutrient mining.

Various authors indicated that data on land degradation and hence soil degradation worldwide are extremely limited, incomplete and often unreliable (Lal, 1994; Lal, 1995;

Pagiola, 1999; FOA, 1999; Wiebe, 2003). Yet, available data suggest that land degradation for many countries particularly for SSA pose considerable threats to sustainability, economic growth and welfare of the people (Pagiola, 1999; FOA, 1999). A review of available figures reveals that about 11 per cent of the global vegetative land is moderately or strongly degraded (Oldman et al., 1990 cited in Pagiola, 1999). Sadly, the extent of degradation is said to be worse in Africa with 320 million ha of land moderately or strongly degraded (Pagiola, 1999; FOA, 1999).

3.1.3 Soil mining and soil quality

In SSA, soil nutrient mining or soil fertility decline is widespread and has aroused considerable concern at regional and international level (Stoorvogel and Smaling, 1990; Ofori, 1995; Sanchez et al., 1997). Stoorvogel and Smaling (1990) estimated the loss of N, P, and K from soil at 10, 2, and 8 kg/ha/year, respectively, in SSA. Similarly, Ofori (1995) indicated that at the current level of agricultural production about 80 kg/ha of nutrients is taken from soil (mainly uptake in crops removed from the land plus nutrient lost through erosion), whereas nutrient application amounts to only 12 percent (10 kg/ha) of the total. Another study by Sanchez et al. (1997) also estimated the annual nutrient losses in SSA at 4.4 million tons of N, 0.5 million tons of P, and 3 million tons of K from its cultivated land. It is therefore evident that current agricultural production in SSA is based mainly on nutrient extraction resulting in nutrient deficiency. Unlike soil erosion, however, soil mining can be relatively easily reversed through the addition of organic and inorganic fertilizers. Nonetheless, in countries such as Ethiopia, the economic impact of soil nutrient mining could be tremendous which warrants careful assessments of the tradeoffs in the use of organic fertilizers such as manure as soil amendments instead of domestic fuel.

Population growth, poverty, insecure land tenure, limited farmer knowledge of appropriate technologies, and limited access to markets, credit and risks associated with use of inputs and new technologies are often cited as the most important causes contributing to the decline of soil fertility in SSA (Reardon and Vosti, 1995; Clay et al., 1998; Shiferaw and Holden, 1998; Pender et al., 2001). Sanchez et al. (1997) indicated that among others, the break down of traditional soil nutrient management practices as a result of increasing pressures on agricultural land prompted by the need to feed increasing population in the face of shrinking land frontier is responsible for nutrient depletion in SSA. However, others argue that population pressure induces households to intensify agricultural production, invest in land improvements and develop land saving innovations eventually resulting in improved resource conditions and possibly improved welfare (Tiffen et al., 1994).

3.1.4 Measuring soil quality

Maintaining and improving the quality of soil resources has been an important policy objective both in the developing and developed world. Soil quality assessment has been an important tool for evaluating the sustainability of soil and crop management practices. However, measuring soil quality has proven to be a difficult task because it varies spatially and temporally and is affected by management and the use of soil resources (Hussain et al., 1999; Magleby, 2002; Stocking, 2003). Consequently, soil quality is viewed in two different ways (Magleby, 2002). The first and traditional view focuses on inherent soil properties and the sustainability of land for various uses such as crop production. The second view focuses on the dynamic properties of soil and the effects of soil management.

The traditional measures used to monitor soil quality and estimate the extent of cultivated land at risk of water erosion include (Magleby, 2002):

1. Land capability and sustainability. This refers to the suitability of land for a particular purpose, such as growing crops or trees, grazing animals, or nonagricultural uses.
2. Prime farmland. Based on physical and morphological soil characteristics such as depth of the water table in relation to the root zone, moisture-holding capacity, the degree of salinity, permeability, frequency of flooding, soil temperature, erodibility, and soil acidity.

3. Productivity. Measures output per unit of input. Productivity can reflect soil degradation if yields decline as soils become degraded and if input use increases to compensate for declines in soil quality.
4. Erodibility. Is a measure of the soils susceptibility to detachment and transport by the agents of erosion (Lal and Elliot, 1994). Soil texture and structure among others determines the erodibility of a given soil. Erodibility index (EI) calculated as the potential erosion divided by the soil tolerance factor have been used in the United States (US) to inventory and classify erosion potential and to determine conservation eligibility.
5. Erosion productivity loss (EPL) measures how many years it would take to remove a topsoil of a given depth at the current rate of erosion assuming all the eroded soil is removed from the field. EPL takes into account an erosion factor, soil depth, and an economic factor expressed as follows:

$$EPL = (1/\text{years of life}) * rent$$

Where, years of life refer to centimeters of sheet and rill erosion per year/centimeter of topsoil in the "A" horizon, and rent refers to the average rental rate of cropland in a specific country.

Although the above measures of soil quality are useful in determining how land might be used or the degree and location of erosion, they are limited in that they are based on physical states of soil and pertain mostly to cropland (Hussain et al., 1999). Some suggest that these traditional measures of soil quality complemented with economic measures such as cash rents and net income could provide policy makers with the minimum information needed to design and target policies for resource management. Larson and Pierce (1994) and Stocking (2003), however, argue that soil quality measures should be broad enough to reflect the various soil attributes or indicators that are controlled or influenced by the various soil functions. Consequently, measures that could better reflect the dynamic properties of soil resources such as soil quality index, soil depth, and regression equations relating various soil quality parameters and soil quality functions are suggested for use to assess soil quality (Larson and Pierce, 1994; Hussain et al., 1999). In the economics of soil conservation literature, soil depth has been used as a proxy to represent the various aspects of soil quality (McConnell, 1983; Saliba, 1985; Barbier, 1990; LaFrance, 1992).

3.1.5 Measuring and predicting the rate of erosion

Soil erosion is a process that is inherent in nature, but the rate of erosion can be drastically increased by intensified agricultural activity. Although, the detrimental effect of soil erosion is undisputable, there still exists disagreement on the extent of erosion, its effect on crop productivity, the environment and its socio-economic impacts. To this effect, modeling soil erosion, the process of mathematically describing soil particle detachment, transport, and deposition on land surface has become an important research area for soil scientists. Erosion models are valuable for the following reasons (Nearing et al., 1994):

- Erosion models can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories, and for regulation.
- Physically based mathematical models can predict where and when erosion is occurring, thus helping the conservation planner target efforts to reduce erosion.
- Models can be used as tools for understanding erosion processes and their interactions and for setting research priorities.

Three types of models are commonly used to measure and predict the rate of erosion: conceptual, physically based and empirical (Nearing et al., 1994).

1. Conceptual Models. Conceptual models focus on predicting sediment yields, primarily using the concept of the unit of hydrology. They usually include a general description of catchment processes. These models provide qualitative and quantitative effects of land use changes. Examples of conceptual models among

others include The Agricultural Non-point Source Model (AGNPS) (Young, et al., 1989) and Agricultural Catchement Research Unit (ACRU) (Schulze, 1995).

2. Physically based models. These are primarily used to represent the essential mechanisms controlling erosion through solving fundamental physical equations describing stream flow and sediment and associated nutrient generations in a catchment. Physically based models provide information that helps to identify the parts of the system contributing to the overall erosion process. It also provides spatial and event specific information (critical seasons or months in which major erosion events occur as well as the critical positions where soil loss is highest). Examples of physically based models among others include the Water Erosion Prediction Project (WEPP), The Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al, 1980), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980), the Erosion Productivity Impact Calculator (EPIC) (Williams et. al., 1984), the Nitrogen-Tillage-Residue Management (NTRM) (Shaffer et al. (1983); and Monitoring Nutrient Flows and Economic Performance in African Farming System (NUTMON) (De Jager, et.al., 1998).

Despite their usefulness, both conceptual and physically based models require considerable data and resources rendering them less suitable for developing countries where the database is generally insufficient.

3. Empirical Models. Empirical models, as the name suggests, are based on observation and are usually statistical in nature. The primary focus of empirical models is in predicting average soil loss. Empirical models have been widely used due to their simplicity, ease of use and low data requirement (Nearing et al., 1994). The most commonly used empirical models are the Universal Soil Loss Equation (USLE), the Revised Soil Loss Equation (RSLE) (Nearing et al., 1994; Lal and Elliot, 1994) and the Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell and Stocking, 1982).

The USLE estimates average annual soil loss from sheet and rill erosion as a function of rainfall, soil erodibility, slope, land cover and management, and conservation practices as follows (Nearing et al., 1994; Lal and Elliot, 1994):

$$A = R * K * LS * C * P$$

Where A=estimated average annual soil loss in metric tones per hectare,

R=rainfall erosivity factor (depending on intensity, quantity, and duration),

K=the soil erodibility factor (a measure of the soils susceptibility to erosion, affected by texture and its stability, and permeability)

LS=the topographic factor (combining the effects of slope length and steepness),

C=surface-cover factor (depending on whether soil is vegetated, mulched, or bare),

P=management factor (relating the soil loss with the given management practices to the losses that would occur with up-and-down slope cultivation)

As such, the USLE is simple to use. However, being an empirical equation it could give unwarranted results if used outside the contexts for which it had been originally devised and calibrated (Nearing et al, 1994; Lal and Elliot, 1994). Since the USLE predicts the amount of soil moved on a field but not the amount removed from a field, estimates of the USLE even under the conditions for which it is designed and calibrated may overestimate the amount of soil actually lost to production (Nearing et al, 1994; Lal and Elliot, 1994). To this effect the USLE is modified to suit the peculiar contexts of countries and are widely used in many countries.

The RSLE retains the basic structure of the USLE, but the algorithms used to calculate the individual factors have been changed significantly. Estimation of the individual

factors has also been computerized (Renard et al., 1994; Rose, 1994). Like its predecessors, the RSLE over estimates soil loss for it does not consider spatial flows.
The other empirical model developed by Elwell and Stocking (1982) for Southern Africa, unlike the two earlier empirical models requires only three parameters for estimation: the rainfall energy interception of each crop, the mean soil loss on a bare fallow plot of known slope and a topographic factor for other slopes. SLEMSA is particularly appealing due to the limited information required for its estimation.

3.2 Causes of divergence between private and social rates of soil depletion

Soil conservation from a practical point of view could be considered as any practice or action taken by the land user in an attempt to reduce the effect of soil erosion by means of biological, mechanical and chemical measures. From an economic point of view, however, soil conservation implies a redistribution of resource use rates into the future, whereas depletion implies a redistribution of resources use rates towards the present (Barbier, 1995). This essentially implies like any other investment decisions, farmers, intending to invest in soil conservation are faced with inter-temporal resource allocation decisions and hence have to consider not only current costs and benefits but also future costs and benefits associated with the investments. In developing countries including Ethiopia, the rate of soil depletion from a social point of view is believed to be excessive and is a cause for concern (Bojo, 1992; Bishop 1995; Barbier, 1995; Eaton, 1996). The divergence between the optimal private rate of soil erosion and the social rate arises from:

1. Externalities. An externality occurs whenever the activities of one economic agent affect the activities of another agent in ways that are not reflected in market transactions. Externalities are thus costs and benefits arising in the process of production and consumption, which are not reflected in market prices. Example of negative externalities arising from soil erosion includes sedimentation of dams and irrigation channels. While society as a group is concerned with both on-site

and off-site effects of soil erosion, individual farmers are primarily concerned with on-site effects. Farm households as rational economic agents equating their private marginal costs and benefits of soil conservation, which do not include off-site externality costs and hence are likely to under invest in soil conservation due to the divergence between private and social objectives concerning the optimal soil conservation level (Barbier, 1995, Bishop, 1995; Shiferaw and Holden, 1999). Consequently, in a setting where there exist significant off-site costs, the optimal private and social rates of soil erosion diverge considerably.

2. Imperfect land and capital markets. Under perfectly competitive conditions prices reflect the marginal scarcity value of using resources. However in most less developed countries, markets for agricultural input and outputs are far from competitive and even totally absent for some assets such as soil quality (Barbier, 1995, Bishop, 1995; Shiferaw and Holden, 1999). For instance, in the highlands of Ethiopia, farmers have only usufruct rights to land, but land is neither traded nor used as a collateral. Consequently, smallholder farmers may not take the full user costs of soil erosion into consideration when making decisions regarding soil conservation investments resulting in too little conservation than society desires. The same applies to capital markets operating in such settings where farmers usually face major imperfections that often raise the opportunity cost of using available funds for making long-term investments in soil conservation. Hence, smallholder farmers facing imperfect capital markets and who often lack access to risk mitigation mechanisms if left on their own may under invest in long term soil conservation structures.

3. Time preferences. Time preference refers to the value people attach to present against future income (Barbier, 1995). Time preference is commonly considered to have two components, pure time preference and the marginal opportunity cost of capital. While pure time preference refers to the people’s attitude to risk and uncertainty as well as to household poverty, the marginal opportunity cost of capital represents the scarcity value of savings and returns to alternative

investments. The discount rate, representing both pure time preference and the marginal opportunity cost of capital, is often used to compare present and future costs and benefits arising from alternative investments (Barbier, 1995; Bishop, 1995). The discount rate employed by private individual farmers in general and smallholder farmers in SSA in particular are considered to be very high compared to what society as a group deems appropriate suggesting individual farmers attach less value to the future and hence degrade the environment much faster than society as a group wishes (Barbier, 1995; Bishop, 1995). For instance, Shiferaw and Holden (1999) in the Ethiopian highlands estimated the nominal discrete rates of time preference among smallholder farmers to be 71 per cent on average. The high time preference displayed by smallholder farmers is believed to be associated with poverty, risk aversion behavior and insecure land tenure. On the contrary, society as a whole having a wider asset base is less risk averse and thus displays lower time preferences. Hence, the optimal rate of soil depletion for society would be much lower than the level chosen by individual farmers (Barbier, 1995; Bishop, 1995).

4. Technological improvements. Obviously, technological innovations are geared either to devise substitutes or increase the productivity of scarce resources (Bishop, 1995). In the short run, technological innovations by increasing the productivity of soil resources (e.g. through the use of improved seeds) or providing substitutes for lost nutrients (e.g. commercial fertilizer) might reduce the economic significance of soil degradation both in the developed and developing countries. However, in the long run, the soil capital being an essential input in agriculture particularly in developing countries where chances for a technological break through is slim, soil degradation will continue to be a potential threat to sustainable agricultural development.

5. Policy incentives. Government intervention in agricultural markets in SSA is widespread and believed to have significant effects on farm level incentives for conservation (Makken, 1993; Barrett, 1991; Adugna and Demeke, 2000). Policy

distortions arising from interventions in input and output markets, exchange rate manipulations, insecure land tenure and imperfect competition often distort the true costs and benefits of soil conservation thereby affect farmer perceptions about the optimal level of soil conservation (Barbier, 1995; Gelan, 2002). Recently, governments in SSA have begun implementing structural adjustment programs to do away with the structural inefficiencies associated with market interventions. However, the effect of such programs on the environment is still debated (Bulte and Soest, 1999). Barbier and Burgess (1992) and Barbier (1995) pointed out that agricultural pricing policies could affect farmer incentives to invest in soil conservation practices in the following ways:

- Higher aggregate crop prices and lower agricultural input costs increase the profitability of crop production, thus encouraging an aggregate expansion of agricultural production onto marginal or more erodible land.
- Changes in the relative prices of crops (and crop inputs) can influence the substitution of more environmentally benign cropping and farm production systems for systems that are more environmentally damaging.
- The variability of crop price inputs can affect farmer’s choice of crops and cultivation practices, and decisions to invest in sustainable land management, by affecting the risks associated with alternative agricultural investments and production systems.

A number of studies have attempted to predict the effect of an increase in either input or output price on farmer incentives for soil conservation (Barrett, 1991; Clarke, 1992; LaFrance, 1992; Bulte and Soest, 1999). However, the results are inconclusive[5]. Therefore, attempts to redress policy distortions to bring about the private rate of soil depletion in line with the optimal social rate of soil depletion need improved understanding of the biophysical and economic processes involved in land degradation (land quality and agricultural production) and the decision-making behavior of farmers shaping that relationship (Pagiola, 1999; Wiebe, 2003).

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[5] Detailed discussions on models and results are provided in section 3.4.1

3.3 Effect of soil degradation on agricultural productivity

As has been indicated in section one of this chapter water erosion adversely affecting soil quality is the most important contributor to soil degradation. Lower soil quality in turn impairs the capacity of soil resources to perform its multiple functions imposing on-site costs to individual farmers and off-site costs to society. On-site effects are those that happen at the site where soil degradation occurs whereas off-site effects are those that happen outside the confines of the farm boundary. While the principal on-site economic impact of soil loss is yield reductions, off-site effects of soil erosion include siltation of irrigation systems, crop failure at low laying areas due to flooding, diminished storage capacity and damage to physical plant in hydroelectric power generation schemes, and water quality deterioration affecting drinking water supplies and the productivity of inland and coastal fisheries (Bishop, 1995; Barbier, 1995). Individual farmers, however, are concerned with the effects of soil degradation on the productivity and hence income on their own farms (on-site costs).

Evidence on the forms, rate and extent of erosion are ample (Lal, 1994; Pierce and Lal, 1994). Also, the detrimental effect of erosion on agricultural productivity is not disputed. However, there is still lack of quantitative data on erosion's impact on productivity. Lal (1994) and Pierce and Lal (1994) noted that the difficulty of understanding, and establishing definitive relationship between fall in soil productivity and erosion has been clouded by a multitude of factors:

1. The magnitude of effect of soil erosion on crop productivity is conditioned by location specific attributes such as soil type, topography, soil management system, and microclimate and crop type. The location specificity of results thus limits extrapolation of results to wider areas.
2. Even if it is possible to collect and assemble location specific data from many locations and over time, the difficulty of partitioning (singling out) the contribution of soil erosion to yield decline out of a multitude of factors such as precipitation poses further problem.

3. The interplay of many of the factors affecting crop yield are also poorly understood.

Nonetheless, great strides have been made to understand the relationship between productivity and soil erosion. Summary of the traditional research approaches used to evaluate erosion's impact on crop productivity and the general conclusions drawn from 50 years of erosion and productivity research in the United States (US) are compiled and provided by Pierce and Lal (1994).

Stocking (1984) noted that much of the erosion-productivity studies have been conducted in the temperate regions. Reviewing the studies in both temperate and tropical regions, Stocking (1984) indicated that absolute yield declines due to erosion appear to be much greater in the tropics than the temperate regions. He further indicated that yield declines in the tropics are worrisome, as initial yields tend to be lower in the tropics than in the temperate regions. A recent review of plot level studies by Stocking and Tengberg (1999) in various parts of the developing world indicated that crop yields generally decline in a negative exponential or logarithmic form with soil erosion, but that both erosion rates and yield impacts vary widely with soil, slope, cover, and other site specific properties. Similarly, a review of costs of land degradation studies by Bojo (1996) showed that productivity losses in SSA varied across countries but generally considered as modest, standing at about 1 per cent or less. Wiebe (2003) reviewing the impact of land degradation on soil productivity showed that the studies so far conducted at regional and global scale suggest that land degradation to date had significant impact on productivity or quality of cropland in some areas, but not others. He further noted that impacts are sensitive to location specific biophysical and economic factors and thus remain unclear at regional and global scales.

3.4 Approaches to measuring effect of soil degradation on income and adoption decision behavior of smallholder farmers

Research on the economics of soil erosion and conservation can broadly be categorized into two categories (Eaton, 1996; Bekele, 2003). The first category of research deals with the application of formal economic models aimed at estimating the costs and benefits of soil conservation and consequently identifies tradeoffs against or in favor of soil conservation. The major contributions of the approach have been in quantifying the benefits of soil conservation thereby providing economic justifications and singling out the impact of specific factors such as prices and the discount rate on land management decisions of a profit-maximizing farmer (Eaton, 1996; Grepurend, 1997a; Bekele, 2003). The second category of research concerned with the behavioral issues is aimed at identifying and quantifying the determinants of factors constraining adoption of soil conservation practices among land users.

3.4.1 Approaches to measuring economic costs of soil degradation

Modeling approaches to the economic analysis of soil degradation and conservation could be categorized as those using normative models and those using positive models (Caswell et al., 2001). Normative modeling approaches based on the principle of optimization posit to estimate the effects of policies that limit input use or the use of certain production management practices. Positive modeling approaches to the analysis of soil degradation control, on the other hand, use econometric methods that involve the estimation of the production technology parameters from observed input and output values. Positive modeling approaches are also used to identify factors that actually affect adoption and assess the importance of those factors on adoption decisions (Caswell et al., 2001).

3.4.1.1 Positive modeling approaches to measuring economic costs of soil degradation

The most widely utilized positive models to estimate and model soil degradation control includes: productivity loss, replacement cost, hedonic pricing and net benefit of conservation. Besides, these models are static in that they are useful to examine equilibrium situations at a point in time.

3.4.1.1.1 Productivity loss approach

The productivity loss approach measures farm revenue foregone due to erosion induced topsoil reductions (Bishop, 1995; Barbier, 1995; Bojo, 1996). The accuracy of this approach is basically as good as the yield estimates resulting from erosion. Bojo (1996) indicated that crop productivity losses due to land degradation could be measured using five different but related methods: expert judgment, inferred soil loss-yield decline functions, directly estimated soil loss-yield decline functions, soil depth loss-yield decline functions and plant growth models. These methods provide critical information on erosion rates and crop yield estimates used to derive functional relationships between topsoil loss and crop productivity. The yield losses are then valued at some assumed future crop prices. Bishop (1995) noted that poorly defined relationships between crop (or livestock) yield and land degradation often limit widespread application and accuracy of this approach. Examples of studies using this approach include works by Bishop and Allen (1989) in Mali and Magrath and Arens (1989) in Java, Indonesia.

3.4.1.1.2 Replacement cost approach

The replacement cost approach measures the on-site economic costs of soil degradation through estimating the costs of additional inputs required for compensating lost nutrients (Barbier, 1995; Bishop, 1995; Bojo, 1996). The logic behind this type of study is to calculate the loss of nutrients (e.g., N, P, and K) and put a value on it by using the equivalent cost of commercial fertilizer. Generally the analysis proceeds in four steps (Barbier, 1995; Bojo, 1996). First, the mean rate of soil loss per hectare is estimated for sample areas of different types of cropland using empirical erosion models such as USLE, RSLE and SLEMSA. Second, the associated nutrient losses are estimated using regressions. Third, the costs of replacing the nutrient losses per hectare are valued in terms of nominal and shadow prices using the cost of the commercial fertilizer replacement. Fourth, the national level area subject to erosion is estimated to derive the gross losses in national income caused by erosion.

The major limitations of the replacement cost approach (Barbier, 1995; Bishop, 1995; Bojo, 1996) include:

- It may over-state on-site costs since it is based on replacing the entire mineral stock, whilst the rate at which nutrients become available for crop growth and the low actual uptake of minerals means that fertility may be maintained without complete replenishment.
- This approach does not take into account the thresh-hold beyond which the effects of erosion are irreversible.
- It is also argued that soil erosion affect several yield determining parameters apart from nutrient losses.

Nevertheless, Bojo (1996) suggested that the replacement cost approach is simple to apply when nutrient loss data are already available. He stressed the need to adjust for availability of lost nutrients to plants. Even then, nutrient loss cost is only a proxy for the actual productivity loss, which could be more or less than the cost of nutrient loss.

As noted above, estimates of the cost of degradation are often based on the value of production foregone or the cost of restoring the land, relative to a benchmark in both cases. A major weakness often cited against both the productivity loss and replacement cost approach is their failure to measure the marginal value of soil quality.

3.4.1.1.3 Hedonic pricing

Hedonic pricing also referred to as the land market approach presupposes that the rental or sale price of land appropriately reflects soil quality differences in a setting where there exists a perfectly functioning market (Bishop, 1995). The approach presents the most direct reflection of a reduction in the discounted present value of the income generating potential of a particular plot of land, relative to alternative investments. The applicability of this approach, however, is limited in most developing countries where land markets hardly exist, property rights are not well defined and land related data are unavailable.

3.4.1.1.4 Net benefit of conservation

Another approach often used to measure on-site costs of land degradation is the net benefit of conservation derived from soil conservation based yield differentials relative to yields on similar control plots without conservation (Bojo, 1992; Bishop, 1995). This approach is basically a conventional cost-benefit analysis (CBA) of returns with and without soil conservation appropriately discounted and compared using appropriate evaluation criteria most often the net present value. Bojo (1992) reviewing 20 studies applied CBA analysis pointed out the following limitations: 1) monetary measures are unethical, 2) overemphasizes the quantifiable, 3) aggregation value over individuals serves to hide conflicts, 4) a problem of the price to be used, 5) results can be manipulated to cover vested interests, and 6) incorrectly assumes rational use of economic results for decision making

Despite these limitations, Bojo (1992) suggested that cautious use of CBA is still beneficial for decision making for soil conservation projects.

3.4.1.2 Normative modeling approaches to measuring economic costs of soil degradation

Most commonly utilized normative models to estimate and model soil degradation control includes: linear programming (LP), dynamic programming and optimal control models. While LP could be formulated both in static and dynamic frameworks, the other two are strictly dynamic. A static optimization model does not consider the dynamics between farmers' decisions to use conservation practices, soil degradation and crop yields. Static decision models are appropriate if current actions do not affect future choices. For example if future nutrient stocks are independent of current levels of crop production practices and soil conservation investments, then static farming strategies are optimal. However, static strategies lead to sub-optimal outcomes if future soil nutrient stocks depend on current erosion levels, farming intensities and levels of soil conservation investment. In contrast, dynamic optimization models consider the inter-temporal interactions between these factors and soil quality attributes (Chiang, 1992; Léonard and Long, 1992).

3.4.1.2.1 Static linear programming models

The static LP modeling approach to soil degradation control analysis uses an optimization framework that links economic factors with biophysical conditions of the soil at a point in time. In these models, optimal solutions are obtained assuming some objective criteria of the decision-maker such as profit maximization subject to various constraints such as technology, resource conditions as well as other household specific conditions (Miranowiski, 1984; Cárcamo et al., 1994). Two limitations of static LP optimization models often raised in the literature are that static LP models are deterministic in that they do not provide for the stochastic nature of the erosion process and its influence on farm income patterns over time. Further more, they are highly simplified versions of real world systems with many computational restrictions.

3.4.1.2.2 Dynamic optimization modeling approaches

As has been indicated in section one of this chapter soil quality is dynamic and continuously subjected to both natural and human induced factors (cultivation and conservation) of degradation and regeneration. Intensified agricultural activities in particular entail a certain level of soil loss over and above would have occurred under natural conditions. This essentially implies current level of agricultural activities affects the stock or quality of soil available for future use. Hence, the effect of reduced soil stock or quality on crop productivity and income is dynamic in that current levels of soil loss or reduction in soil quality affect not only current levels of agricultural productivity but also future productivity and income.

Dynamic optimization models, unlike static optimization models which provide a single optimal magnitude for every choice variable considered, trace an optimal time path for each choice variable in a given time interval (Chiang, 1992; Léonard and Long, 1992). It also provides opportunity to integrate economic variables with biophysical processes and hence allow incorporating feedback effects of economic factors on management decisions. Dynamic optimization models are thus suitable for modeling the inter-temporal effects of soil degradation and conservation for both soil degradation and conservation are dynamic in nature (Burt, 1981; McConnel, 1983; Grepperud, 1997a; Brekke et al., 1999; Kruseman and Bade, 1998; Barbier and Bergeron, 1999; Ruben and Kuyvenoven, 1998). The three widely utilized dynamic optimization models often employed in modeling soil conservation are dynamic LP, dynamic programming and optimal control models.

3.4.1.2.2.1 Inter-temporal linear programming models

Owing to the limitations of the static LP models, a dynamic formulation of LP models with an explicit incorporation of the time dimension have become popular for decision support purposes to simulate the effect of socio-economic factors such as population pressure, market pressures, and agricultural policies on soil degradation, crop productivity and farm income at farm, village or regional level (Ruben and Kuyvenoven, 1998; Kruseman and Bade, 1998; Barbier, 1998; Barbier and Bergeron, 1999). Ruben and Kuyvenoven (1998) indicated that LP models combined with biophysical models, often referred to as bio-economic models, integrating technological and behavioral elements are useful in resource depletion studies and help identify the right incentives that could enhance farmers' adoption of more sustainable cropping practices.

Among the noteworthy empirical studies, which applied dynamic LP models, include Kruseman and Bade (1998), Barbier (1998), Barbier and Bergeron (1999), Shiferaw and Holden (1999) and Shiferaw and Holden (2000).

Barbier (1998) used an approach combining a dynamic LP model of economic behavior with a biophysical model of plant growth and the condition of the soil to simulate a village's response to population and market pressure. Likewise, Barbier and Bergeron (1999) developed a bio-economic model combining dynamic LP with a biophysical model and applied it at a watershed level to investigate intensive vegetable pathway of development and generate possible policy actions for similar contexts.

Shiferaw and Holden (2000) used a non-separable farm household model based on a dynamic LP to investigate the role of alternative policy instruments for soil conserving land. This model was used to identify a production plan which maximizes annual net return defined as current net returns less the present value of future income loss caused by land productivity decline due to soil erosion subject to various farm level resource supply and behavioral constraints. In another study, Shiferaw and Holden (2001) applied whole farm LP model to identify a production plan that maximized annual income defined as current net returns (on-farm and off-farm) less the present value of future income loss caused by yield losses resulting from soil erosion subject to various farm level resource supply and behavioral constraints.

The major limitation inherent in optimization models including dynamic LP is the absence of a detailed specification of the decision making procedures at the producers level, the neglect of other objectives than profit maximization, and the assumption of perfect markets. Besides resource allocation is strictly based on best technical means (Ruben and Kuyvenoven, 1998).

3.4.1.2.2.2 Dynamic programming models

A dynamic programming model is based on Bellman's principle of optimality, which states, an optimal policy has the property that whatever the initial state and decision are, the remaining (abridged sequence) must still be optimal in its own right- as an optimal path from its own initial point to the terminal point (Chiang, 1992; Léonard and Long, 1992). Dynamic programming formulation of a natural resource use problem consists of two features (Chiang, 1992; Léonard and Long, 1992):

- It embeds the given control problem in a family of control problems, with the consequence in solving the given problem, the entire family of control problems are solved.
- For each member of this family of problems, primary attention is focused on the optimal value of a functional rather than on the properties of the optimal state path as in the calculus of variation or the optimal control theory.

Application of dynamic programming models in empirical analysis of the economics of soil conservation, however, is limited due to the fact that the solution of continuous-time problems of dynamic programming involves the use of partial differential equations. Besides, partial differential equations often do not yield analytical solutions (Chiang, 1992; Léonard and Long, 1992).

Nonetheless, Burt (1981) analyzed the optimal level of crop rotation and rate of organic matter using a dynamic programming framework in the US. Burt (1981) assuming farmers maximize the present value of net returns over an infinite time horizon modeled the inter-temporal choice of soil conservation practices using two state variables (topsoil depth and percentage of organic matter in the top six inches of soil) and one control variable (crop rotation-percentage of wheat area). Using data from the 1950's and empirically solving the model, Burt (1981) showed that at higher wheat prices 87.5 per cent of the rotation would be in wheat for almost the entire domain of the two state variables. When a lower price is assumed, however, the percent of land under wheat decreased as percentage of organic matter decreased. He concluded that higher grain prices worsen soil erosion problems. Burt's model, however, was criticized for the way the control variable (percentage of wheat area) was specified as it unambiguously implies higher prices induce more soil loss. The model was also criticized for failing to consider conservation practices explicitly.

Another study that utilized dynamic programming optimization modeling approach is that of Hopkins et al. (2001) in the US. Recognizing that both nutrient mining and soil erosion as important sources of soil degradation, the authors investigated the likely economic implications of productivity losses from both irreversible physical topsoil degradation and reversible nutrient mining. In this model, level of fertilizer input and residue management are control variables whereas topsoil depth and the condition of soil nutrients are state variables. Assuming that producers maximize the expected present value of net returns from corn production, the model chooses the optimal levels of fertilizer and residue management given that the dynamics of the state variables, soil depth and condition of soil nutrients jointly determine corn yield. Hopkins et al. (2001) applying their model to nine soil types of the US drew the following conclusions. First, given soils with different characteristics such as initial properties, susceptibility to degradation, differential yield responses to management and etc., dynamic optimal economic strategies could not be inferred from physical responses but can be inferred from associated economic implications. Second, optimal residue management responds more to nutrient management than erosion. Third, substantial gains are possible from nutrient management than reducing topsoil loss due to erosion.

3.4.1.2.2.3 Optimal control models

Optimal control models are based on the mathematical programming techniques of microeconomics with a time dimension. A typical optimal control formulation consists of two features. First, it should consist of three types of variables namely: state, control and time. Second, optimal control theory has as its primary aim the determination of the optimal time path for a control variable (Chiang, 1992; Léonard and Long, 1992). The optimal control formulation of dynamic optimization problems is therefore preferred for modeling soil degradation as it enables direct determination of the optimal time path of control variables, a management/policy instrument that enables one to influence the state variable(s).

Among the noteworthy theoretical and empirical studies, which applied optimal control models include McConnell (1983), Saliba (1985), Barbier (1990), Barret (1991), LaFrance (1992), Clarke (1992), Grepperud (1997b), Goetz (1997), Brekke et al. (1999) and Nakhumwa (2004). The works of McConnell (1983) laid the foundation for the application of optimal control theory to the analysis of the economics of soil degradation control. Latter works, basically, are either modifications or extensions of McConnell's (1983) model. A brief review of the most influential optimal control models in the soil conservation literature are given below.

In his optimal control model, McConnell (1983) assumed farmers maximize the present value of the stream of net profit plus the market value of their farm at the end of the planning horizon. This formulation clearly indicates that the returns to the farm from the use of soil has two components: the value of soil as an input to agricultural production over time contributing to profits and the stock of the soil resources at the end of the planning period affecting the resale value of the farmer's land. McConnell specified agricultural inputs and soil loss as the decision (control) variables and soil depth as a state variable. Crop yields were modeled as a function of soil depth, soil loss, and input use and further assumed to be concave and twice differentiable. Crop yields increase with soil loss, soil depth and input use with diminishing returns to crop production associated with each of these variables. The equation of motion, change in soil depth, was specified as the difference between the natural rate of regeneration and soil loss. McConnell (1983) analytical results provided the optimality conditions for a profit-maximizing farmer:

- Private individual farmers use variable inputs until the value of its marginal product equals their cost.
- Soil loss will be incurred until the value of returns obtained from additional soil loss equals the implicit cost of using the soil. The cost of soil loss in foregone

future profits is the change in the productivity and sale value of the farm caused by having less soil.

- The implicit cost of soil loss should grow at the rate of discount less the soil's contribution to current profits.

The implication of the above first order conditions is that any change which would increase the costs of soil loss or decrease the benefits would lead to a reduction in soil loss and vise-versa (Eaton, 1996). Further performing comparative analysis for three alternative tenure arrangements (owned family farms, rented family farms and corporate farms), McConnell (1983) concluded that the private rate of soil depletion converges to the socially efficient level under efficient capital markets. Eaton (1996), however, argued that McConnell's conclusions might not be applicable to most developing country settings characterized by pervasive market imperfections or even missing markets. Furthermore, McConnell's model is criticized for ignoring conservation efforts as a decision variable and inclusion of soil loss as a control variable (Saliba, 1985). The use of soil loss as a control variable is considered unrealistic in a farm level model as farmers do not choose soil loss directly but do so by choosing suitable management practices such as crop rotation and other soil conservation practices. Despite the limitations and criticisms leveled against McConnell's model, it remained vital in pointing out how farmers react to changes in discount rates and for further setting out the direction for future research (Saliba, 1985; Eaton, 1996).

Saliba (1985) acknowledging the contributions made by preceding soil conservation models argued that earlier models had at least three limitations: failure to explicitly specify conservation efforts, inadequate specification of erosion-soil productivity linkage, and lack or inadequate specification of cropping intensity. Saliba (1985) further suggested that a complete farm level soil conservation model should include the following variables and functions:

- Functional relationships which capture the impact of farm management choice (the control variable) on soil attributes (the state variable);

- State variables reflecting changes in soil depth and other productivity related soil characteristics;
- Erosion-productivity linkages relating changes in soil characteristics to crop yields; and
- Crop yield functions incorporating both soil productivity and management variables that would allow substitution possibilities between soil and other inputs.

Accordingly, the optimal control model developed by Saliba (1985) included three decision variables namely, conservation effort, an index of management intensity and crop intensity and one state variable, soil depth. Like its predecessors, Saliba's (1985) model posits that farmers maximize the present value of the stream of net revenues from their farms plus the market value of the land at the end of the planning horizon by choosing crop rotations, level of management intensity and soil conservation effort. Though, Saliba (1985) provided the first order necessary conditions for optimality, the author did not numerically solve the model.

Barbier (1990) extending McConnell's (1983) optimal control model by including a soil conservation variable as a control variable showed that farmers will invest in soil conservation up to the point where the marginal cost of investing in soil conservation equals the marginal benefit. The model also pointed out that an increase in the discount rate lowers farmers incentives to use soil conservation practice thus result in greater soil erosion.

Later models, Barrett (1991), Clarke (1992) and LaFrance (1992) all emphasized the role of price incentives in soil conservation decisions but their models differ in the treatment of soil conservation inputs as a decision variable and the specification of erosion (soil loss) functions.

LaFrance (1992) considered the case where cultivation increases the rate of crop production but degrades the soil whereas conservation reduces the rate of crop production and increases the rate of soil growth. LaFrance further assumed that the erosion function is independent of soil depth (stock). The objective of the rational farmer was assumed to be maximization of the discounted net present value of the commodity prices from crop production. LaFrance's results showed that the impact of price change on rate of soil degradation depends on the relative strength of cultivation over conservation. If the effects of cultivation dominate the effects of conservation in the soil dynamics, an increase in the price of the crop accelerates the rate of soil degradation in the short run and decreases the long-run stock of the soil resources. On the other hand, if the effects of conservation dominate the effects of cultivation, an increase in the price of the crop decelerates the rate of soil degradation in the short-run and increases the long-run stock of the soil resources.

Clarke (1992) focused on soil-conserving investments, which do not affect crop yields directly. He further assumed that soil quality is depleted in proportion to the current intensity of production as measured by output implying the magnitude of soil loss increases with soil depth. The farmer is assumed to maximize the discounted value of profits over an infinite time by selecting time paths for investment in soil quality and the variable input. Clarke (1992) claimed that the effect of output price change depends not only on current profits but also on the existence of viable soil conservation technologies as well as the complementarity/substitutability of inputs and hence effects of output price change may go either way. He showed that in a setting where viable conservation technologies are available and where the use of variable inputs and conservation investments are complementary, favorable input and output price movements result in the intensive use of more of each input and lower equilibrium level of soil degradation. On the other hand, if inputs are substitutes even in a setting where there are viable soil conservation technologies, soil quality may decline.

Barrette (1991) considered soil depth as a state variable and soil loss due to cultivation as a decision variable. Barrett (1991) results demonstrated that agricultural price reforms would have only modest effects on soil conservation.

Grepperud (1997a) indicated that a common feature of earlier models, those explicitly considered soil conservation as a control variable, is that conservation efforts are assumed to be effective only in the time period they are implemented. However, although some conservation practices may have time limited effects (must be implemented every year to have a beneficial effect) others such as terraces, stone and earth bunds could be viewed as investments in land having an anticipated life beyond the current period. To this effect, Grepperud (1997a) extending LaFrance's (1992) model introduced soil conservation investment as having a lasting impact beyond the time they are implemented as a decision variable. As in LaFrance's model, this model assumes that productive inputs degrade the soil whereas larger stock of conservation structures lower soil and fertility losses. While the results of this model (investment model) are similar to earlier models, the investment model differs in that conservation inputs are employed until their marginal cost equals their marginal benefit where marginal benefit is defined as the gain associated with a higher stock of soil measured by the shadow price of structures.

The models so far discussed considered crop mix as an exogenous variable and assumed the farmer produces only one crop. Goetz (1997), however, analyzed the optimal and social inter-temporal path of soil use considering crop choice itself as a soil conservation practice in addition to the conventional inputs. The farmer was assumed to maximize the present discounted value of net returns from a choice of an appropriate mix of inputs and crops having differing erosive potential. Goetz's results showed that if farmers recognize the productivity impacts of soil loss and maximize their longrun net returns, the optimal strategy is predominantly characterized by the cultivation of just one crop. At the steady state, however, a mix of crops is cultivated. Comparative analysis of the steady state showed that policies affecting prices have an uncertain effect implying either taxing or subsidizing the price does not seem to be a viable option for improving the longrun soil stock.

Another study worth considering utilizing optimal control model for economic analysis of soil degradation is that of Brekke et al. (1999) who modeled the inter-temporal soil use combining a soil scientific model of soil productivity and degradation with economic variables. Farmers are assumed to maximize soil wealth measured as the present value of soil rent by choosing labor input, capital and fertilizer input. They developed two versions of an optimal control mode: 1) the soil mining model which presupposes soil nutrient mining as the overriding land degradation problem thus treating the soil capital as a renewable natural resource and 2) an expanded model which considers land degradation resulting from both nutrient mining and top soil loss due to erosion. Brekke et al. (1999) model is particularly appealing in that it explicitly recognizes both soil nutrient mining and topsoil loss. However, they did not include soil conservation practices in their model.

More recently, Nakhumwa (2004) employing an inter-temporal optimization framework that included soil conservation practices investigated the impact of soil degradation due to nutrient mining on the productive value of smallholder land in Malawi. The model was constructed on the premise that the impact of irreversible physical soil degradation due to erosion poses less of a threat to smallholder agriculture in Malawi and that there is no significant interaction between fall in soil productivity and erosion induced decline of soil physical structure. The model maximized the discounted sum of the stream of net benefits from the use of soil quality stock to produce agricultural output by choosing optimal levels of fertilizer and labor for production as well as optimal levels of conservation efforts through the choice of labor and capital inputs for conservation. The study revealed that given current farmer production practices, soil degradation due to nutrient mining represents a significant cost to smallholder agriculture in Malawi, which amounts to USD 21 per ha.

All of the models reviewed above have attempted to characterize the factors that should be included in a farm level economic model with various degree of success. The studies share some similarities

- All the studies attempted to ascertain the rationale behind farmers' decision to tolerate a certain amount of erosion;
- Most of the modeling works pertain to the situation of developed countries;
- With few exception many of the works are purely analytical;

- All focused on on-site impacts of soil erosion;
- The objective function in all of the models reviewed is similar, the maximization of a stream of discounted net returns from farming. However, they differ in the choice of the variables and the specification of the soil loss (erosion) function;
- Most previous optimization studies with the exception of Brekke et al. (1999) and Nakhumwa (2004) have not made a distinction between soil degradation resulting from topsoil loss (irreversible soil physical degradation) and soil degradation due to nutrient mining (reversible decline in soil quality). Consequently, estimates from these models could be biased either way.

3.4.2 Approaches to modeling adoption of soil conservation and soil nutrient management practices

In developing countries including Ethiopia, a lot of effort and resources have been devoted to generate and disseminate agricultural technologies to smallholder farmers. Despite the efforts, however, adoption of improved production technologies including soil conservation and soil fertility enhancing practices remained low (Yirga et al., 1996; Demeke et al., 1997; Shiferaw and Holden, 1998; Gebre Michael, 1999; Alene et al., 2000; Gebremedhin and Swinton, 2003). Rather, smallholder farmers continued to rely on traditional production technologies, yield levels stagnated at low levels, the soil erosion problem persisted while per capita food production continued to fall as population increased. It was soon realized that soil degradation and its accompanying effect of low productivity is not simply a technical issue, rather complex including socio-economic and behavioral factors and requires a change in approach. Consequently, the need for a systems approach became apparent in order to deal with the complex nature of low and declining agricultural productivity which necessitated biophysical and social scientists to join hands thereby make agricultural research more relevant to the situation of smallholder subsistence farmers (Mekuria, et al., 1992). The role of smallholder farmers in the technology generation and transfer process was formally recognized and took a new precedence known as participatory technology development and transfer; and the need to develop a better understanding of the conditions which encourage adoption of recommended agricultural technologies became a priority.

Following a change in approach and focus, a number of technology adoption studies were initiated and implemented in developing countries including Ethiopia pertaining to production technologies (Kebede, 1990; Yirga et al., 1996; Hassan et al., 1998a; Hassan et al., 1998b; Adesina and Baidu-Forson, 1995; Baidu-Forson, 1999; Alene et al., 2000; Dadi, et al., 2001; Fufa and Hassan, 2003). The attention provided to analysing the determinants of investments in soil conservation by smallholder farmers in Ethiopia, however, remained low (Shiferaw and Holden, 1998).

Feder *et al.* (1985) have summarized the vast amount of empirical literature on production related adoption and indicated that the constraints to adoption of a new technology may arise from many sources, such as lack of credit, inadequate farm size, unstable supply of complementary inputs, uncertainty and risk. Factors conditioning smallholder farmers' investment in soil conservation and soil fertility management summarized in the literature include: perception of the soil degradation problem, profitability of the proposed technology, household and farm characteristics, attributes of the technology and institutional factors such as land tenure, access to markets, information and credit (Ervin and Ervin, 1982; Norris and Batie, 1987; Pagiola, 1996; Shiferaw and Holden, 1998; Hassan et al., 1998a; Hassan et al., 1998b; Lapar and Pandey, 1999; Kazianga and Masters, 2001; Bamire et al., 2002; Gebremedhin and Swinton, 2003; Nakhumwa and Hassan, 2003; Bekele and Drake, 2003). Others have also argued that besides the above factors risk considerations also affect the rate of adoption of an innovation (Grepperud, 1997b; Shively, 2001; Fufa and Hassan, 2003).

Among the noteworthy empirical studies that investigated the factors conditioning smallholder farmers' decision to invest in soil conservation in developing countries include that of Pagiola (1996) in Kenya, Pender and Kerr (1998) in India, Lapar and Pandy (1999) in Philippines, Kazianga and Masters (2001) in Burkina Faso, Nakhumwa and Hassan, (2003) in Malawi, Shiferaw and Holden (1998), Gebremedhin and Swinton

(2003) and Bekele and Drake (2003) in Ethiopia. These studies highlighted the magnitude and direction of influence of factors hypothesized to condition adoption as largely area specific and their importance varied among countries, between agro-ecologies within countries and among sites within agro-ecologies. Attempts to generalize the relative importance of individual constraints across farm groups, regions and countries are thus unlikely to be useful.

Although important contributions have been made by previous adoption studies in identifying the factors constraining smallholder farmers benefiting from recommended technologies and suggesting ways of improving policy design, the studies, however, were not free from limitations. A fundamental problem characterizing all adoption studies is the absence of economic theory that could serve as a basis for the selection of the determinants of technology adoption decision variables. Although in principle a farmer's investment in conservation practices could be derived from the maximization of his/her utility function, the fact that the arguments of the utility function are not known makes derivation difficult (Norris and Batie, 1987).

Ghadim and Pannell (1999) noted that despite the huge number of adoption studies conducted in the last 30 years, the results in the field remained short of expectations. They indicated that most of the statistical models developed have low levels of explanatory power despite the fact that a long list of explanatory variables is used. Furthermore, the results from different studies are often contradictory regarding the importance of any given variable. Ghadim and Pannell (1999) citing Linder (1987) pointed out four shortcomings responsible for the inconsistent results obtained by most of the empirical studies of agricultural innovations:

- Failure to account for the importance of the dynamic learning process in adoption
- Biases from omitted variables
- Poor model specification
- Failure to relate hypotheses to a sound conceptual frame work

The use of binomial and multinomial qualitative choice models in the analysis of adoption of technologies is well established in the adoption literature (Feder et al., 1985). One purpose of qualitative choice models is to determine the probability that an individual with a given set of attributes will make one choice rather than an alternative (Green, 2000). The two most popular functional forms used for adoption models are the probit and the logit models. Dimara and Skuras (2003), however, acknowledging the contributions that previous adoption studies using dichotomous adoption decision models had made for the design of improved policies, they contended that dichotomous adoption models have got inherent weakness. They indicated that despite the fact that most decision-making processes concerning innovation adoption involve a multistage procedure, static adoption models often consider the process as a single stage. Dimara and Skuras (2003) argued that the basic tent of a single stage decision making process characterizing dichotomous adoption decision models is a direct consequence of the full information assumption embedded in the definition[6] of adoption. However, the full information assumption is often violated and hence analysis of the adoption decision using logit, probit and Tobit models may suffer from model misspecification (Dimara and Skuras, 2003).

Over the years a number of authors have tried to overcome these limitations in a number of ways. Notable modifications and extensions of the standard adoption decision model are briefly discussed below:

1. Byerlee and Hesse de Polanco (1986) and Leathers and Smale (1991) suggested a sequential adoption decision model.
2. Ghadim and Pannell (1999) assuming that previous adoption models did not adequately considered the dynamic learning process suggested the use of a dynamic adoption decision model, which includes farmers' personal perceptions, managerial abilities and risk preferences.

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[6] According to Feder et al (1985) individual adoption (adoption at the level of the farm or firm) is defined as the degree of use a new technology in the long-run equilibrium when the farmer has full information about the new technology and its potential.

3. Fufa and Hassan (2003) using a stochastic production function showed the importance of risk effects of factor inputs on production behaviour of smallholder maize growers in Ethiopia.
4. Dimara and Skuras (2003) assuming that adoption of innovations involves a multistage process and drawing from literature that quite a good deal of the sample population in previous adoption studies did not have the necessary information and level of awareness concerning the new technology (violating the full information assumption) suggested a partial observability model.
5. Likewise, Gebremedhin and Swinton (2003) recognizing that the decision to invest in soil conservation involves multiple stages and these decisions may be independent (or sequential) suggested the use of a double hurdle model where a logit or probit regression on adoption (using all observations) is fitted followed by the use of a truncated regression on non-zero observations.
6. Hypothesising that the variables determining the probability of using a conservation technology may be different from the factors affecting intensity of use, Nakhumwa and Hassan (2003) used a selective Tobit model to simulate the adoption decision behaviour of smallholder farmers as a two-step process. Empirical results showed that for smallholder farmers in Malawi, the factors that determine the probability of use of a conservation technology (ridge marker) may be different from that determine the intensity of use (Nakhumwa and Hassan, 2003).

3.5 Summary

The notion that soil is a natural resource capital that could provide sustained flows of productive and environmental supporting services over time if managed properly is well recognized in the literature. Furthermore, the potential threat that soil degradation has posed on the income and welfare of smallholder farmers as well as on national food security in SSA is not disputed. However, the magnitude of the threat that soil degradation poses on current as well as future income to individual farmers and the national economy and how best to address the problem is not well known. Consequently, maintaining and improving the quality of soil resources have become an important policy objective particularly in SSA where the majority of the population ekes out its living from working the soil. Apparently, a lot of resources have been devoted to soil degradation control research and development related efforts.

Previous soil degradation control research efforts could be categorized into two. The first category of research includes studies aimed at improved understanding of the technical relationships involved in soil degradation processes (e.g. soil erosion and the physical, chemical and biological properties of soils) as well as among soil quality decline, soil erosion and fall in land productivity. Although, research in this category have made important strides to uncover the relationship between productivity and soil erosion there still remains much uncertainty concerning the magnitude and extent of the relationship due to methodological and empirical difficulties involved in measurement and estimation. The second category of research includes studies on economic costs of soil degradation and hence on the economic benefits of soil conservation. The later category could further be divided into two: those dealing with estimating the economic costs of soil degradation control and those studies dealing with the analysis of the adoption decision making behavior of land users.

The bulk of the studies that have attempted to model the long-term impacts of soil degradation are concentrated in the developed countries. Both positive (econometric) and normative (optimization) models have been developed to estimate and model the economic costs of soil degradation. The positive models, which were mainly static did not account for the inter-temporal use of the soil capital (ignore the dynamic nature of the soil degradation and soil conservation investments). Normative models included static as well as dynamic formulations. Most of the dynamic models were developed under the presumption of the existence of a competitive or near competitive land market rendering them less suitable to the conditions of developing countries where land markets are incomplete or non-existent. Furthermore, despite the fact that both nutrient mining and water induced topsoil loss are important in SSA including Ethiopia, most of the studies with the exception of Brekke et al. (1999) and Nakhumwa (2004) have not made a distinction between soil degradation resulting from topsoil loss (irreversible soil physical degradation) and soil degradation due to nutrient mining (reversible decline in soil quality). While the former has considered both sources of soil degradation, conservation effort was not explicitly included as a decision variable. The study by Nakhumwa (2004) included soil conservation effort as a decision variable but focused on the reversible feature of soil degradation. Available estimates were therefore useful to the extent that they indicate the magnitude of the problem but could not provide the full costs that continued soil degradation will have on a country's economic development. Hence, there is a need for both theoretical and empirical studies that employ a dynamic optimization framework accounting for both irreversible soil physical degradation and reversible soil nutrient mining in order to assess the inter-temporal trade-offs (the true costs of soil loss incurred relative to the value of output expected) that farmers face in their production decisions in SSA.

Also, despite the large number of adoption studies carried out in SSA, the attention provided to the analysis of soil conservation adoption and soil nutrient management practices to date is minimal. Various authors have pointed out that most of the statistical models developed and used to investigate the adoption decision behaviour of smallholder farmers have low levels of explanatory power despite the fact that long lists of explanatory variables are used. Furthermore, the results from different studies are often contradictory regarding the importance of any given variable mainly due to differences in the types of soil conservation technologies extended to farmers, agro-ecology and socio-economic situations. This inconsistency of results, therefore, underscores the importance of agro-ecology based empirical adoption studies using well-specified adoption decision models. Recognizing the fact that smallholder farmers in the highlands of Ethiopia manage several plots of land and that soil fertility management and soil conservation practices involve choices among several technological options, this study, applied econometric models that account for simultaneity of choices and interdependent decisions.