Economics of Soil and Water Conservation

Theory and Empirical Application to Subsistence Farming in the Eastern Ethiopian Highlands

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Doctoral thesis
Swedish University of Agricultural Sciences
Uppsala 2003

Acta Universitatis Agriculturae Sueciae
Agraria 411

ISSN 1401-6249
ISBN 91-576-6433-1

Tryck: SLU Service/Repro, Uppsala 2003

Abstract

Wagayehu Bekele, 2003. *Economics of Soil and Water Conservation: Theory and Empirical Application to Subsistence Farming in the Eastern Ethiopian Highlands.* Doctoral Thesis.
ISSN 1401-6249, ISBN 91-576-6433-1

The Ethiopian highlands, inhabited by the vast majority of the Ethiopian human and livestock populations, are under continuous threat from soil erosion. Land degradation induced by soil erosion is considered to be among the major factors responsible for the recurrent malnutrition and famine problems in Ethiopia. Conservation efforts during recent decades have succeeded neither in triggering voluntary adoption of conservation practices nor in mitigating soil erosion problems. The purpose of this thesis is, therefore, to understand the socio-economic aspects underlying soil and water conservation decisions in the context of subsistence farmers in the Eastern Highlands of Ethiopia.

In articles I, III, and IV, the farmers' decision problem is modeled as a utility maximization problem, and econometric models are used to link the statistical model of observed data and the economic model. Stochastic dominance criteria are used, in article I, to determine whether adoption of a conservation practice results in higher expected grain yield and income and/or reduced variability. Limited dependent variable econometric models are used in articles III and IV in order to determine factors that influence farmers' decisions on soil and water conservation, and their preference for types of development intervention. In article II, the decision problem is modeled as an intertemporal net benefit maximization problem, and a dynamic programming optimization model is applied to determine the optimal path of investment in soil and water conservation.

Findings in article I suggest that conservation results in higher expected grain yield and income, but does not support the hypothesis that conservation unambiguously results in less variability than no-conservation. In article II, it is shown that the optimal path of investment in soil and water conservation depends on the discount rate and grain prices. The results also suggest that erosive agricultural practices yield higher return in the short-term, whereas conservation yields a higher and sustainable return in the long-term. The need to design incentive mechanisms that encourage farmers to have a longer planning horizon are among important suggestions proposed in articles I and II.

Results, in article III, suggest that specific physical conditions of plots and socio-economic characteristics of farm households influence the soil and water conservation decision behavior of farmers. Article IV suggests that the perceived priority of farmers with regard to agricultural problems and socio-economic characteristics, determines their preference for the type of development intervention. The results also suggest that there exists a complementarity between different interventions and hence a need to address them simultaneously to ensure a higher return from interventions. An important lesson to be drawn from articles III and IV is that differences in farming conditions and complementarities between policy programs need to be noted in any intervention program.

Key words: Soil erosion, soil and water conservation, subsistence farming, farmers' preferences , decision behavior, development intervention.

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To my father Bekele Tafesse, to my brother Seble Bekele, to my sister Mestewat Bekele, and to my father-in-law Debebe Negesse. May their gentle and loving souls rest in peace.

Acknowledgements

Completing a thesis under pressure of time is not an easy task. However, starting the route of education is more difficult for those who are from those far corners of the world remaining unwired to modern means of communication. I would, therefore, like to express my gratitude to my parents, who offered me the opportunity of education they never had, and to all those who supported me, in one-way or another, throughout my schooling life.

I am deeply indebted to my supervisor Lars Drake for his ongoing encouragement and all-round support and guidance throughout my Ph.D. studies. I am equally indebted to Lars for the academic freedom I enjoyed, the friendly working atmosphere he offered and his hospitality. I would also like to thank Dodo Thampapillai, my co-supervisor, for his assistance and guidance in one of my articles. I am grateful to the Department of Economics, SLU, which has hosted me and provided me with a good congenial working environment during my stay in Sweden. All of the articles in the thesis have gained from comments and suggestions of many people at the department, personally or through our regular departmental seminar sessions. I would, therefore, like to thank all the staff, formerly or currently associated with the department, who have contributed either academically or socially in the realization of this thesis. I prefer to adopt the principle of nobody mentioned, nobody forgotten.

I am thankful to Sida/SAREC for funding this study under the joint Swedish University of Agricultural Sciences (SLU) and Alemaya University (AU) Ph.D. training and capacity building project. My thanks also go to Alemaya University for nominating me to be trained under the project, granting me study leave, and facilitating my field research work. I am very grateful to the Ethiopian Ministry of Agriculture (MoA) for providing me access to the Soil Conservation Research Project (SCRP) database and other relevant documents. My thanks to the Oromia National Regional State Bureau of Agriculture, Western Hararghe Zone Bureau of Agriculture and, Tulo Woreda Bureau of Agriculture, for their cooperation and assistance in facilitating my field research work. My deepest thanks goes to the farmers in Hunde-Lafto area for their genuine cooperation, and sacrifices of time they made for discussions and replies to survey questionnaires. The survey work would have been impossible without the assistance of the devoted and courageous enumerators Jemal Abrahim, Osmail Oumer and Ahmed. I am particularly thankful to Jemal Abrahim, who has been working as field assistant in the SCRP Hunde-Lafto research site, and whose knowledge about the project and acquaintance with farmers in the area significantly facilitated my fieldwork.

Finally my utmost thanks go to all my family members who paid the cost of separation and endured the test of loneliness during my long absences. I would particularly like to thank my wife Bisrat Debebe and my son Akalewold Wagayehu, without whose understanding and support I would not have supported the burden and survived the pressure of completing this thesis.

Articles appended to the thesis

This thesis is based on the following articles, by Wagayehu Bekele except where otherwise stated. Article III is accepted for publication in *Ecological Economics*. Article I, II and IV are in submission to *Environmental & Resource Economics*, *Land Economics* and *Agricultural Economics*, respectively.

I. Stochastic dominance analysis of soil and water conservation in subsistence crop production in the Eastern Ethiopian Highlands: Case study of the Hunde-Lafto area.

II. Optimal path of investment in soil and water conservation for subsistence food production in the Eastern Ethiopian Highlands.

III. Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia: A case study of the Hunde-Lafto area. *Wagayehu Bekele & Lars Drake*.

IV. Aanalysis of farmer preferences for development intervention programs: A case study of subsistence farmers from the Eastern Ethiopian Highlands.

Contents

1. Introduction

1.1. Background

Economic use of soil resources is a fundamental concern because land is an essential input in agriculture, in the sense that no output will be produced without its use. This is particularly true for Africa and many other developing countries where non-labor inputs in agriculture are negligible and agricultural land is the critical resource and the basis for survival of the vast majority of the population (Barbier, 2003). Agriculture in these countries is not only an economic activity but also a way of life. Thus, agricultural land is a cornerstone upon which the welfare of society is built. In the process of using land, farmers expose the land to various forms of degradation - physical, chemical, and biological. As a result, this crucial resource is under continuous threat and its long-term productive potential is being impaired. In economic terms, land degradation causes a decline in the attributes of land in relation to specific functions of value. When considered from a global perspective, decline in food production from a specific country or region due to land degradation, or any other factor, may not have a significant effect on food supply because of the potential substitution from other producing areas. However, the effect could be quite significant and might pose a threat to food security of large number of poor people and to local economic activity in regions or countries where the problem is most serious (Scherr & Yadav, 1996).

Land degradation may occur at any time in any geographical region of the planet (van der Leeuw *et al.*, 2000). It is limited neither by space and time nor by a particular natural circumstance. However, specific types of land degradation problems and the level of severity exhibit considerable differences across various parts of the world. For example, water quality problems appear to be the primary environmental issues in developed countries, in Eastern and Western Europe and North America, whereas soil erosion is the most crucial issue in Australia, Asia, Africa, and South America (Napier *et al.*, 1995). Owing to variations in the type and severity of land degradation problems among different regions and countries, the focus of abatement efforts and the strategies to overcome the problem should be different. The consequence of the problem and the emphasis to be placed on the problem depends, among others, upon the significance of the agricultural sector in the national economy. The economy of many developing countries, including Ethiopia, is heavily dependent on agriculture, and the livelihoods of the vast majority of their populations depend directly or indirectly on this sector. This dependence on agriculture increases the vulnerability of the economy of these countries to problems related to land degradation.

1.2. Problem statement and purpose

Among the various forms of land degradation, soil erosion is the most important and an ominous threat to the food security and development prospects of Ethiopia and many other developing countries. It induces on-site costs to individual farmers, and off-site costs to society. Due to the presence of externalities arising from soil erosion, market prices do not reflect resource scarcity and individual farmers will have insufficient incentives to practice soil conserving agricultural practices. Accelerated soil erosion can be reduced by a combination of proper land management systems and appropriate soil and water conservation efforts. Incentives to promote soil and water conservation measures are, therefore, among appropriate areas of intervention to mitigate the adverse effects of erosion. Physical soil conservation structures technically have the potential to reduce soil loss by decreasing overland flow of water and to mitigate yield variability by reducing moisture stress on plant growth through retention of rainwater that would otherwise be lost to runoff.

As a result of increasing awareness that soil erosion reduces yield and income and poses a threat to household food security, substantial efforts have been directed towards finding appropriate soil and water conservation measures for low-income farmers (Shively, 1999). The economic argument to rationalize this public investment in soil and water conservation is that it improves resource allocative efficiency in the absence of market incentives for erosion control. However, in spite of rapidly growing awareness about soil erosion, its physical causes and effects, together with increased understanding of methods of protecting and multiplying conservation efforts in the past few decades, erosion remains widespread and adoption of conservation practices by farmers remain limited (Kerr, 1998). This could be explained by the fact that underlying the immediate biophysical causes of soil erosion are socio-economic factors that dictate whether farmers practice soil conserving or erosive agricultural practices. In other words, socio-economic forces could constrain the desirability and adoption of technical solutions. The need for better understanding of these factors, for the purpose of designing policy and programs that promote conservation behavior, necessitates socio-economic studies of soil and water conservation.

The purpose of this thesis is, therefore, to analyze the socio-economic aspects of soil and water conservation (SWC) as it applies to subsistence farm households in the Eastern Ethiopian Highlands. The specific research questions for the thesis, and how these questions are addressed in the thesis, are given below.

1) Does soil and water conservation improve crop yield and farm income and/or reduce farmers' exposure to risk due to variability in yield and income?
2) What is the optimal path of investment in SWC in subsistence crop production?
3) What are the socio-economic factors that influence farmers' SWC decisions behavior?
4) What are the farmers' perceived priority agricultural problems, preferred areas for development intervention, and which factors affect the preference for alternative types of intervention?

In article I, determination whether investment in SWC results in a higher yield and farm income and/or reduces farmers' exposure to risk due to variability is made by applying a stochastic dominance criterion. A dynamic programming optimization model is employed in article II to determine the optimal path of investment in SWC and the effect of specific factors on the optimal path. A multiple-choice decision model, multinomial logit, is used in article III to determine agro-ecological, socio-economic and institutional factors that influence farmers' SWC decisions. In article IV, the agricultural problems and preferences for development intervention given priority by farmers are ranked, and factors influencing the preferences are determined using a random utility model.

1.3. Scope and limitations of the study

This study is based on micro level economic analysis of soil erosion and conservation in the Hunde-Lafto area, Western Hararghe Zone of Oromia National Regional State, Ethiopia. The findings could be extended to other areas with similar agro-ecological and socio-economic settings with a certain level of adjustment. Generalization to wider areas and larger scales, however, requires precaution and supplementation of results with further studies because of differences in the farming environment. Soil erosion, and consequently soil and water conservation, has both on-site and off-site effects. Only the on-site economic aspects are dealt with in this study. Soil conservation principles imply limiting both the detachment and transportation of soil particles from soil aggregates by erosive agents. Types of conservation measures dealt with in this study are only those that can help to limit the transportation of detached soil particles by water.

The effect of soil erosion and hence of conservation is a slow process that requires some lapse of time to be felt. This implies the need for an extended period of time for research activities to monitor the impacts. The time requirement is far beyond the scope granted for this Ph.D. study. Therefore, my search for information, particularly for articles I and II, had to be satisfied with available secondary data generated from experiments that were neither designed nor organized in a way suitable for economic analysis. Furthermore, the time series data from the Soil Conservation Research Project (SCRP) used in the analysis showed some disruptions due to the security problems that prevailed in the area during the period of the study. This resulted in the use of estimates and proxies for some variables. The results, therefore, need to be understood in this context and can only be taken as indicative, rather than being considered as definitive.

1.4. Structure of the thesis

The thesis is organized in six sections. In the following section (section two), economic aspects of soil erosion are discussed. Section three provides a brief account of soil erosion and conservation in Ethiopia. In section four, literature in the area of economics of soil and water conservation is reviewed. Summaries of the four articles annexed in this thesis are presented in section five. Finally, the contributions of the thesis and suggestions for future research are discussed in the conclusions provided in section six. The four articles are annexed to the thesis.

2. Economics of soil erosion

Soil erosion is a two-phase process consisting of the detachment of individual particles from the soil mass and their transport by erosive agents, such as water and wind. When sufficient energy is no longer available to transport the particles a third phase, deposition, occurs (Morgan, 1986). The principle of soil conservation is, therefore, to limit the detachment and transportation of soil particles by erosive agents. Soil erosion is a natural process that has taken and will always take place. It even occurs on lands with grass or forest cover, and has been taking place long before agricultural civilization started (Brown, 1981). The normal rate of erosion under natural vegetation is, however, in approximate equilibrium with the rate of soil formation (Troeh *et al.*, 1999). Problems arise when the natural process of soil erosion is accelerated due to human interventions that result in deviations from the equilibrium. Among the different human activities that accelerate soil erosion processes, agriculture is the most important and most soil erosion occurs on cultivated lands (Hudson, 1986).

2.1. Historical perspective

Throughout the history of human civilization, soil erosion has had both positive and negative effects. It has positively contributed to the early civilizations of mankind that developed in the valleys of Tigris, Euphrates, Nile, Indus, and the rivers of China (Hudson, 1986; Wild, 1993). These civilizations arose on irrigated alluvial plains and were dependent upon flood deposits of silt for continued fertility that provided plant nutrients. For example, the loss of soil and dissolved nutrients from Ethiopia has for millennia enriched the soils of Egypt (Blaikie & Brookfield, 1987). On the other hand, continual soil erosion from agricultural lands has led some to poverty and has forced others to migrate. Under increasing population pressure that resulted in expansion of cultivation, farmers were forced to move from one place to other. The ensuing competition for land and water rights often destabilized relations between tribes and countries and created tensions and even war (Bentley, 1985). Studies on the effect of erosion on early civilizations (cited in Hudson, 1986) argued that the major cause of the downfall of many flourishing empires was soil degradation.

Although erosion has occurred throughout the history of agriculture, it intensified during recent decades and has become a major social concern. It has been recognized as a serious natural resource problem and has been a subject of policy concern since the beginning of the 1930s, particularly after the establishment of the Soil Conservation Service (SCS) by the United States (US) Congress in response to alarm generated by the high erosion rates observed during the famous Dust Bowl days (Walker & Young, 1986). It has gained momentum since the 1950s, due to inputs from widespread mass poverty, famine, and malnutrition in many developing countries caused by problems related to land degradation. Concerns prompted by reports that increasing soil erosion is intensifying air and water pollution problems and reducing the productivity potential of croplands brought about the adoption of the Soil and Water Conservation Act of 1977 in the US (Lee, 1980). Increasing concern with the problem, global recognition that land degradation in many countries is nearing the point of no return, and the urgent need to sensitize and secure commitments from members of the international community, have led to adoption of the World Soil Charter in 1982 by the Food and Agricultural Organization of the United Nations (FAO). This charter set forth principles for wise, productive, and protective land use to ensure the welfare of future generations. Nevertheless, increasing rates of soil erosion persist and depletion of this natural resource continues.

2.2. Accelerated depletion of natural capital asset

Capital is a stock of real goods with the potential to produce a flow of benefits or utilities in the future. Natural capital, then, is the stock of goods derived directly from nature that have the potential to contribute to the long-term economic production and welfare of societies (Barbier, 1998). Like other natural capital, soil is a stock of goods derived directly from nature that has the potential to contribute to the long-term economic productivity and welfare of societies (*ibid*). As with financial capital, natural capital can be measured in stocks and flows, although in physical rather than monetary units. These natural capital stock and flow values may be converted into monetary units with application of resource prices to the physical quantities, although this exercise is often problematic due to imperfections in resource markets that lead to distorted prices.

Natural capital stocks are commonly divided into renewable and exhaustible categories based on their capacity for reproduction and growth at a significant rate when viewed from man's economic time scale. Renewable resources are capable of regenerating themselves, as long as the environment in which they are nurtured is favorable (Dasgupta & Heal, 1979). Upsets in this nurturing environment may lead to a loss of regeneration capacity and thus to deterioration of the resource quality. In order to ensure sustainable production, the use of renewable resources should not exceed the natural rate of regeneration.

The issue of whether agricultural soil is a renewable or exhaustible natural resource depends on the resource management system employed in its use. Theoretically, topsoil could be considered as a renewable natural resource because it regenerates through the natural process of soil formation. As discussed by Dasgupta & Heal (1979), arable land is considered as a renewable resource so long as it is utilized carefully, and regenerates itself over the annual cycle. Concerns arise when the rate at which it is depleted or eroded through cultivation is faster than the rate at which it regenerates. Renewable natural resources could be transformed into the category of exhaustible resources through mismanagement (Hartwick & Olewiler, 1986; Howe, 1987 cited in Anderson & Thampapillai, 1990). Under conditions where the annual natural soil formation is largely exceeded by the annual soil loss to erosion, the soil stock could be turned into a potentially exhaustible resource. In view of the often-slow soil formation rates and high rate of soil erosion in arid and semi-arid regions, the soil resource is best characterized as an exhaustible resource (Anderson & Thampapillai, 1990; Barbier & Bishop, 1995; Hu *et al.*, 1997). In the case of Ethiopia, where the rate of soil loss from cultivated land exceeds the soil formation rate by a factor of 4 to 10 (Hurni, 1988), soil can be characterized as an exhaustible resource without loss of generality. Therefore, like other exhaustible natural resources, careful decisions on soil use and management over time are of paramount importance in order to maintain the productive capacity of the soil. When soil depletion occurs as a result of loss of soil nutrients and organic materials, it may be replenished through the application of organic or inorganic sources of nutrients or appropriate agricultural practices. But erosion reduces the topsoil and results in a loss of soil depth, which is an irreversible effect. This is because conservation efforts will only mitigate further soil loss, and generally do not reverse the situation and will not restore the soil depth (LaFrance, 1992). Also with regard to nutrient loss, however, when soil is used continually without replenishment in arid and semi-arid regions it will gradually lead to desertification and loss of the productive natural capital stock (de Graff, 1993).

Human activities exposing the soil to erosion and inducing depletion of this natural capital asset of society include deforestation and removal of the natural vegetation, overgrazing and erosive agricultural activities. Among the human induced soil degradations, loss of topsoil through water erosion is the most important that occurs in almost every country under a great variety of climatic and physical conditions, and land use systems. According to Oldeman *et al.* (1991), water erosion contributed about 47% of human induced land degradation in South America, whereas about 34%, 15%, 3%, and 1% are attributed to nutrient decline, wind erosion, water logging and salinization, respectively.

According to Speth (1994 cited in Pimentel *et al.*, 1995), about 80% of the world's agricultural land suffers moderate to severe erosion, and 10% suffers slight to moderate erosion. Soil erosion occurs at varying rates and with varying degrees of severity in different parts of the world, and even in different locations within the same country. Rates are generally higher in Asia, Africa, and South America, averaging 30 to 40 t/ha/yr, and lower in the United States and Europe, averaging about 17 t/ha/yr (Barrow, 1991 cited in Pimentel *et al.,* 1995). Substantial differences also exist within regions. For example, de Graaff (1993) showed that annual soil loss from cropland in selected developing countries ranges from 1 – 800 t/ha/yr depending on the slope of land under cultivation, the type of crop grown and other environmental factors. His estimates for some African countries included in the study show soil loss due to erosion of 7 t/ha/yr for Lesotho, 72 t/ha/yr for Kenya, 3–35 t/ha/yr for Burkina Faso, and 14-221 t/ha/yr for Nigeria, depending on the location of the plot and the type of land use. Such estimates, though not definitive, can give insight into the problem. They clearly indicate that the natural stock of soil, which is the main productive asset of poor farmers in developing countries, is under threat of rapid depletion due to soil erosion and requires considerable attention. In addition to its natural capital asset depleting effect, soil erosion also induces immediate on-site and off-site effects.

2.3. On-site effects

In the process of physical removal of productive topsoil, soil erosion results in immediate on-site effects. On-site effects are those that happen at the site where erosion occurs. Soil erosion results in damage to the crop on the ground, imposing costs on individual farmers. From the economic point of view of individual farmers, the most important and immediate on-site effects of soil erosion are decline in current and potential crop and livestock yields that are translated into income losses. This threat of soil erosion may also be reflected in the need to use a higher level of input to maintain soil productivity in order to achieve the same level of yield. The decline in crop and livestock yield engendered by soil erosion is due to the removal of fertile topsoil, and decline in fertility of the soil as a result of loss of essential nutrients and organic matter.

Whether the on-site effect of soil erosion is a major social concern or not is being debated. Burt (1981) and other sources (cited in Lal 1998), argue that the economic consequence of on-site effect of erosion is of less economic consequence because these are easily compensated by soil and crop management options and additional input use. Further, it is argued that unlike other negative externalities arising from agricultural activities, the on-site costs of soil erosion are borne first and foremost by the farmer himself rather than by the public at large. Hence, the farmer has vested interest in looking after his soil resource and managing erosion. Provided that farmers have good information about the impact of agricultural production decisions on land quality, and that agricultural input and output markets, including markets for land and credit, are competitive, soil erosion does not present any environmental externalities. Others argue that on-site cost of soil erosion is an important social concern. This is because in most developing countries, where the problem of soil erosion is more serious, there is a general lack of competitive market. Land and credit markets are poorly developed and there is a poor information system, hence resulting in failure of market system to protect the land (Shortle & Abler, 1999). As a result, the full cost of soil erosion is borne by society. In addition, Pimmentel *et al.* (1995) and Brown (1995 cited in Lal, 1998) argue that the on-site effects of soil erosion are extremely severe and a major economic problem at all scales due to the global shortage of prime arable land, use of marginal or fragile soil resources, harsh climate, and non-availability or non-affordability of the essential inputs needed. As further pointed out by Pimmentel *et al.* (1995), the use of large amounts of fertilizer, pesticides, and irrigation to offset the on-site effect of erosion have the potential to create pollution and health problems, destroy natural habitats, and contribute to high energy consumption and an unsustainable agricultural system.

The economic importance of the on-site effect of soil erosion is context specific that depends on the natural climate, level of economic development and, importance of agriculture in the national economy. The impact may be more dramatic in developing countries where agriculture is the dominant economic sector, and where external inputs to compensate for loss of soil fertility cannot be afforded by subsistence farmers. Geographically, the effect is more pronounced in the tropics than under temperate conditions due to the relative fragility of tropical soils, or more extreme climatic conditions (Barbier & Bishop, 1995, Enters, 1998a). According to Southgate *et al.* (1984), because the on-site impacts are often more dramatic in developing countries than they are in North America, the cost of soil erosion, and thus the benefits of conservation, may be substantial in developing countries despite relatively low average returns to agriculture. Some illustrative figures on the on-site cost of soil erosion help to give an insight into the magnitude of the problem. Barbier & Bishop (1995) estimated the annual cost of land degradation in developing countries to vary from less than 1% to more than 15% of their respective GNP, with the estimate for Ethiopia being from 6% to 9% of the GNP. The estimate of the direct on-site cost of soil erosion for the United States economy, given by Stalling (1957 cited in Dregne 1982), amounted to about $ 750 million per year. According to sources cited in Pimentel *et al.* (1995), on-site cost of erosion in India due to fertilizer carried away in sediments is estimated at about $245 million, and on-farm loss of productivity due to erosion in Java is estimated at about $315 million.

2.4. Off-site effects

Decline in on-site crop and livestock yields is not the only problem that stems from soil erosion. When the soil leaves the boundary of the field due to erosion and enters another field or watershed, it may have negative or positive effects. These are off-site costs of soil erosion on society at large. These effects could be negative or positive. The negative off-site effects of soil erosion caused due to inundation and siltation involve damage to present and future crop productivity; damage to civil structures and other industries, and adverse change in the environment (Lal, 1998). The negative off-site effects of soil erosion inducing damage to water reservoirs, and pollution of water bodies and air, attracted the more attention than the on-site effects from researchers and policy-makers in the developed world. In general, the off-site effects of soil erosion can be grouped in to three classes. These include effects on productivity, effect on water reservoirs, and environmental effects.

a) Effects on Productivity. Soil leaving the boundary of the field due to erosion and entering other fields will have positive or negative effects on the present and future crop productivity of plots downstream. The negative effects include crop burial by sediment deposition, crop damage by increased frequency and depth of floods and water lodging due to accumulation of overland flow in depressions. The future productivity of crops will also be affected due to long-term changes in soil quality as a result of water lodging and sediment deposition in depressions. This is particularly true when the fertility of soil at the deposition site is better than the sediments left by flood. Some indirect effects, such as supply of fertile soil by deposition of silts in depressions, may have positive effects on crop growth at the deposition site. When the fertility of the soil at the deposition site is lower than the sediment deposited, sediment deposits will have a positive effect in providing nutrients for better growth of plants. The overland flow water deposited in depressions may also contribute to the recharge of the ground water in the deposition sites. Although these off-site effects of soil erosion are important, quantified information on their economic impact is scarce.

b) Siltation Effects. Siltation of water reservoirs used for irrigation, hydroelectric power, and other purposes, is among the negative off-site effects of soil erosion that attracted more research and policy attention. Relatively, more quantified research information has become available on the cost of damage to water reservoirs caused due to siltation than other off-site effects of soil erosion. This might be due to the relative ease of measurement and assignment of economic value to the damage, or due to its immediate impact on the day-to-day life of society. Reliability of data on estimates of soil losses by erosion is often questioned due to differences in sampling methods and measurement techniques. Inferences and extrapolation of results at different scales also pose a serious methodological problem (Stocking, 1987). Such problems sometimes lead to estimates of soil loss from the same location differing in several orders of magnitude (Dregne, 1982; Stocking, 1987; Enters, 1998a; Hopkins *et al.*, 2001). As a result, estimates of the damage it causes may also differ. Nevertheless, available estimations could provide some indications about the magnitude of the economic problem involved.

Available estimates on the off-site costs of soil erosion are mostly for the United States. Pimentel *et al.* (1995) estimated the overall annual erosion-caused damage to the United State's economy at $44 billion, and the annual cost of investment in conservation to reduce erosion to a sustainable rate of 1 t/ha/yr to about $8.4 billion. This justifies that investment in conservation pays off. Clark (1985) estimated the annual net damage cost of erosion, directly related to sediments, to range from $3.0 to $3.5 billion in 1980, out of which the contribution of erosion from croplands is estimated to be from $1.0 to 1.2 billion. The annual construction cost of new sediment pools to protect reservoirs ranged from $300 to $800 million during the period of 1963 – 1981 (Crowder, 1987). Out of this amount, the impact of sediments from cropland on reservoir capacity was estimated at about $197 million.

c) Environmental Effects. Well-functioning soils provide much of the world's food and fiber production, highest quality freshwater and the biological diversity of terrestrial and aquatic ecosystems that contribute to the wealth of human societies (Richter & Markwitz, 2001). Many of these ecological services of soil that are essential for society can be damaged due to soil erosion from agricultural lands. Sediments and agrochemicals carried in overland flow along with the sediments may be deposited in water bodies and cause water pollution. As a result, aquatic ecosystems can be seriously affected, as pollutants can destroy spawning areas, food sources, and habitats as well as directly damage fish and other aquatic wildlife (Clark, 1985). As a result, both commercial and recreational fishing activities will be affected. Furthermore, land degradation and gradual desertification induced by soil erosion have impacts on terrestrial biodiversity as well since these processes could threaten the survival of many plant and animal species.

Soil erosion also causes air pollution and contributes to the problem of global warming. World soils are important pools of active carbon and play a major role in the global carbon cycle. Topsoil displaced from the terrestrial ecosystem due to erosion contains carbon. Part of this carbon content will be easily decomposed, mineralized and released into the atmosphere (Lal, 1995; Lal *et al.*, 1995; Eswaran, 1995). Therefore, physical displacement of soil through erosion processes from the terrestrial ecosystem results in a carbon flux into the atmosphere, adding to the problem of global warming. Estimates of the cost of environmental damage caused by soil erosion are hard to come by. However, the scarcity of damage cost estimates of soil erosion on air, water bodies, biological communities, recreational values, and other impacts does not imply that the impacts are small. The presence of off-site costs arising from soil erosion and other institutional problems apparent in developing countries result in market failures and affect farmers' incentives for investment in land protecting activities.

2.5. Market failure

The first fundamental welfare theorem establishes the perfectly competitive case as benchmark for thinking about outcomes in market economy. An economic outcome is said to be *Pareto optimal* if it is impossible to make some individuals better off without making some other individuals worse off. This concept offers a minimal test that any social optimal economic outcome should pass (Mas-Colell *et al.* 1995). Under the assumption of a complete set of markets, with publicly known prices, and a perfectly competitive market, where every agent acts as a price taker, the competitive market outcome will be *Pareto optimal*. However, the assumptions for *Pareto optimality* to hold are often violated in the real economic world resulting in market failure, and this is particularly true under the conditions of developing countries. In such conditions, market equilibrium cannot be relied on to yield *Pareto optimal* resource allocation.

Market failure occurs when market prices encourage people to produce, consume or invest in ways that are economically optimal for the individual but not economically optimal for society as a whole, *i.e*, market prices do not reflect scarcity of resources and hence lead to non-optimal resource use. The implication of this on soil resource management in developing countries is that individual farmers lack incentives to take into account the off-farm costs and/or benefits generated due to their farm practices in land use decisions. The presence of market failure results in insufficient incentives for individual farmers to practice soil conserving agricultural practices and encourages further soil erosion and land degradation. This leads to non-optimal resource allocation and utilization and necessitates government intervention to ensure resource allocative efficiency. Market failures in these countries occur due to the presence of off-site costs arising from soil erosion, lack of information, risk and uncertainty, poor specification of property rights, poorly developed or non-existent credit and insurance markets, as well as other institutional factors (Kerr, 1998). The economic rationale for public investment in soil and water conservation is that it improves resource allocative efficiency in the absence of market incentives for erosion control. The following paragraphs discuss these factors in further detail.

a) Erosion Externalities. An externality is present whenever the well-being of a consumer or the production possibility of a firm is directly affected by the action of another agent in the economy (Mas-Colell *et al.*, 1995). The off-site costs or benefits resulting from erosion represent externalities caused due to soil erosion.

These are off-site costs and benefits borne due to erosion that are not reflected in the market price because they affect other economic agents in the society, not the ones whose actions have induced the cost. When externalities are present, farmers employing erosive practices gain all the benefits but do not bear all the costs, and farmers investing in soil and water conservation bear all the costs but do not gain all the benefits. As a consequence, the resource use plan of privately rational farmers may lead to non-optimal results from societal perspectives. Private costs and benefits from soil use do not equal the social costs and returns because individual farmers take into consideration only the direct costs and benefits accruing to their farm, whereas from societal economic perspectives all direct and indirect costs and benefits from any activity need to be taken into account. Therefore, the presence of off-site costs that result in deviation between private and social optimal rates of soil erosion results in market failure to protect the soil resource. Investments in conservation, under this situation, are more likely to benefit the community more than the individual farmers themselves. Hence, the need to close the gap between the individual and social optimal rates of soil erosion requires appropriate government policy intervention

b) Lack of Information. In order for a market system to operate competitively and allocate resources efficiently, the role of information is crucial. Farmers evaluate and use information to make production and management decisions. As this applies to soil and water conservation, the long-term period over which the effect of soil use and management decisions on productivity takes place implies the need for information on the future. When there is a lack of information, the long-term impact on productivity of soil erosion processes may not be known and this may delay farmers from taking informed decisions about soil and water conservation. In many developing countries access to such information to farmers is often limited.

c) Property Rights. Soil conservation, from an economic perspective, implies saving soils for future use, i.e., redistribution of soil use rate into the future. Soil depletion by erosive agricultural practices, on the other hand, implies redistribution of soil use rate to the present (Barbier, 2003). When there is poor specification of property rights and tenure insecurity over important assets such as land, farmers are more likely to have short planning horizons so that long-term effects of erosion on productivity will have less influence on land use decisions. Therefore, they may employ erosive agricultural practices that will deplete more soil at the present at the expense of the future. In addition, the most reliable indicator that a farming household can have of the effect of soil erosion on future land productivity is through land price (*ibid.*). However, in countries like Ethiopia where land is state-owned and not tradable, the market mechanism cannot help to provide information about the user cost of soil erosion, and hence leads to market failure.

d) Credit Market. Farmers may adopt profitable soil and water conservation measures if they have sufficient funds of their own or if they have access to credit. High initial investment and maintenance cost of structures is often more than affordable by subsistence farmers and, therefore, require access to credit. However, for farmers in developing countries lack of access to credit creates disincentive for investment in soil and water conservation. Credits from formal institutions are inaccessible to subsistence farmers due to lack of collaterals, particularly in cases like Ethiopia where land is state-owned and hence cannot be used as a mortgage for loans. Credits from local moneylenders are often at a very high rate and on a short-term basis that discourages investment in soil and water conservation from which returns are expected over the long-term. Therefore, even when appropriate technologies are available for soil conservation, farmers cannot adopt them where there is such a lack of credit market.

e) Risks and Uncertainties. The fact that most farmers, whether they farm in the developed or developing world, are averse to risk is generally accepted and well documented (Anderson & Thaampapillai, 1990). It is particularly worrying for subsistence farmers in developing countries operating at the margin of economic survival. Risks and uncertainties in soil and water conservation arise from insecure land tenure and lack of information on future markets and performances of alternative land use systems. Even if farmers have complete information, uncertainties about the appropriate type of conservation practice and the optimal level of investment introduce elements of risk that curtail investment. The general lack of rural credit and insurance markets in developing countries further aggravates the effect of risks and uncertainties on soil and water conservation decisions.

f) Time preferences. Farmers are expected to rationally analyze the effects of conservation activities over time and compare the effects with expected income without conservation. Within this framework, individuals facing similar erosion problems may reach different conservation investment decisions depending on their individual time preferences or discount rates and the length of their planning horizon (Lee, 1980). A lower discount rate and a longer planning horizon will be favorable for conservation decisions as these result in a higher net present value of future benefits and allow sufficient time to recoup conservation investment. The preferences of farmers are also affected by individual socio-economic characteristics of the household as well as other institutional factors that affect market operation. The above-discussed factors, such as access to credit, information, land tenure, risks and uncertainties, as well as the poverty status of households, will affect the individual farmer's choice of discount rate and planning horizon. Generally, subsistence farmers in developing countries will have high rate of time preference and will employ a higher rates of discount than the society even in the absence of market distortion. This is because asset basis for society are wider than for individuals and will allow minimization of risks through diversification. As discussed by Barbier (2003), a farmer's discount rate may be affected by the pure time preference rate, reflecting his attitude to risk and uncertainty as well as the level of household poverty, and the marginal opportunity cost of capital, which represent the scarcity value of savings and returns to alternative investments. This divergence between private and social time preference leads individuals to discount future benefits excessively and thus to consume assets that society as a whole would prefer to have conserved (*ibid.*).

3. Soil erosion and conservation in Ethiopia

The natural process of soil erosion has been accelerated in nearly all of Africa during the 20th century due to a marked increase in human and livestock population resulting from the relatively recent provision of veterinary and human health services in rural areas (Dregne, 1982). The increase in livestock and human population brought with it increased deforestation, overgrazing, shortening of fallow periods between cropping, expansion of cultivated land into marginal and steeply sloping terrains, and inevitably resulted in accelerated erosion. As a result, soil erosion has become of serious environmental concern in the sub-humid regions of Africa, including Kenya, Ethiopia, Tanzania, Nigeria and other countries lying along the south side of the Sahara (Grove, 1974 cited in Dregne, 1982). As indicated earlier, much of soil erosion takes place from cultivated lands and its effects are reflected in the agricultural sector.

3.1. Agricultural sector

Ethiopia, with a total land area of about 1.14 million square km and about 67 million inhabitants, is the second most populous country in Africa. The country also has the largest livestock population in Africa (Gronvall, 1995). Ethiopia has great geographical diversity with altitudes ranging from areas about 100 meters below sea level in the Denakle depression to 4620 meters above sea level at the Ras-Dashn mountain peak. This geographical diversity results in climatic conditions that show extreme variability and significant microclimate variations within a relatively small distance. Agriculture is the dominant economic sector in Ethiopia that accounts for about 45% of the GDP, 85% of the employment and 90% of the foreign exchange earning. The vast majority of the population, about 85%, live in rural areas and derive their livelihoods directly or indirectly from agriculture. The agricultural sector is predominantly subsistence in nature, in which the major part of farm production is for household consumption. Small-scale subsistence farms, with an average land holding of less than one hectare, occupy about 90% of the cropped land and produce around 95% of the total agricultural output (Gronvall, 1995). A mixed farming system, involving both crop production and livestock rearing activities, is the dominant type of production system. Food crop production is predominantly raid-fed. Only about 3% of the total food production in the country comes from irrigation agriculture, whereas only about 5% of the potential irrigable land in the country is under irrigation (FDRE-MoFED, 2002).

The highest concentration of human and livestock populations in Ethiopia is in the highlands (over 1500 meters above sea level) where the climate is favorable for rain fed crop cultivation and provides a wide range of environments suitable for simultaneous crop and livestock production. The highlands in Ethiopia, that constitute about 43% of the total land area of the country and about 90% of the land suitable for rain fed agriculture, are inhabited by about 88% of the human and 60% of the livestock population (Constable, 1985, cited in Hurni 1993). These highlands, which are home to the vast majority of the human and livestock populations, have been under continuous threat from various forms of land degradation, compromising the livelihood of the population and challenging the relevance of rural development policies pursued by successive governments.

3.2. Soil erosion

Among different forms of land degradation processes in Ethiopia, soil erosion by water is the most important environmental problem that poses an ominous threat to the food security of the population and future development prospects of the country. Soil erosion is not a new phenomenon in Ethiopia; it is a process as old as the history of agriculture in the country (Hurni, 1988, 1989). This process has been accelerated by population growth that has brought with it more deforestation. With the increase of population pressure, development of agricultural production involves an increased risk of land degradation through deforestation and expansion to new marginal lands that are often fragile and susceptible to erosion. This is particularly true in Ethiopia where non-labor inputs in agriculture are negligible and farmers often seek to increase food production through expansion of cultivated land. The process of erosion is further aggravated by the intensity of the tropical rainfall and the dissected nature of the terrain, with nearly 70% of the highlands having slopes in excess of 30%, that favor severe soil erosion once the vegetation is reduced (Gronvall, 1995).

Ethiopia has been described as one of the most serious soil erosion areas in the world (Blaikie, 1985; Blaikie & Brookfield, 1987) with an estimated annual soil loss of about 42 t/ha/yr from croplands, resulting in an annual crop production loss of 1 to 2% (Hurni, 1993). Repeated problems of famine and starvation, currently well-known images of the country, have been attributed at least partly to this phenomenon of soil erosion (Eckholm, 1976; Blaikie, 1985; Hurni, 1989, 1993). In many parts of the country, recurring starvation and famine are still parts of rural life. According to the 1985 Ethiopian Land Reclamation it is estimated that only 20% of the total area of the Ethiopian highlands have relatively minor problems of erosion; 76% are significantly or seriously eroded and 4% have outstripped their capacity to be of any value for production. It was estimated that, if this trend continues, about 18 % of the highland will be bare rock by the year 2010, which corresponds to about 10 million people who will not be able to produce food from the land (Dejene, 1990; Gamachu, 1990). The ever-increasing food deficiency and severity of famine problems in the country seem to confirm this forecast. Almost 75% of the Ethiopian Highlands were estimated to need soil conservation measures of one sort or another if they are to support sustained cultivation (FAO, 1986, cited in Wood 1990). The eastern Ethiopian highland, which is the subject of this study, is among the severely degraded highlands of Ethiopia (Hurni, 1988).

3.3. Conservation efforts

Crop failure due to land degradation and climatic variability is not a new phenomenon in Ethiopia. As discussed above, soil erosion is a process as old as the history of agriculture in the country. High rainfall variability characterized by a quasi-periodic fluctuation, and consequently drought situations, has occurred throughout human history in the country (Haile, 1988). However, the problem of land degradation attracted the attention of policy-makers only after the consequences became felt during recent decades. As a cumulative effect of continuous land degradation, ever-increasing population pressure, and inappropriate development policies, the country for the first time became a net food importer by the late 1950s (Aredo, 1990). Since the devastating famine in 1973/74, Ethiopia became food aid dependent. After the 1973/74 famines, that coincided with and/or triggered a change of regime in the country, the government has initiated a massive program of afforestation and soil conservation with the support of international organizations. Packages of soil and water conservation programs were prepared for implementation through Food-For-Work (FFW) schemes.

Between 1976 and 1988, conservation and afforestation undertaken by the Ethiopian peasants, under the FFW program, amounted to some 800 000 km of soil and stone bunds on croplands, about 600 000 km of hillside terraces for afforestation of steep slopes, some 100 000 ha of closed areas for natural regeneration, and many activities of land rehabilitation (Hurni, 1988, 1989). World Food Program (WFP) support for soil conservation and afforestation activities in Ethiopia reached about US$50 million per year in 1987 (*ibid.*). Aside from the introduced soil and water conservation measures, reports indicate that peasants have been aware of problems related to soil erosion and developed different indigenous soil and water conservation practices that sustained agriculture for centuries. These include different conservation practices in the Northern Highlands (Dessalegn, 1987 cited in Hoben, 1996); well developed terracing systems of Konso in southern Ethiopia (FAO, 1990); ditches in Northern Shewa in the Central Highlands (Alemayhu, 1996); and different techniques in the Eastern Highlands (Asrat *et al.*, 1996). It appears that these traditional practices were not given due consideration in the massive soil conservation and afforestation campaign under the FFW schemes.

The massive campaign in soil conservation and afforestation, with a huge layout of financial and manpower resources under the FFW, does not seem to have succeeded either in triggering widespread voluntary adoption of the practices by farmers in a sustainable manner or in solving problems related to soil erosion. In the wake of the announcement of an economic policy change in March 1990, and the subsequent change in government in May 1991, farmers removed most of the conservation structures built on their plots and cut down the trees planted under the project (Shiferaw & Holden, 1998; Admasse, 1995; Hoben, 1996; Asrat *et al.*, 1996; Alemayehu, 1996). The soil erosion problem persists and increased mass poverty in rural areas prevailed. The often localized indigenous conservation practices did not match the severity and intensity of the soil erosion problem in the country. The development and widespread use of all sorts of conservation practices have been curtailed due to disincentives created by the political, institutional, and economic environments in the country.

3.4. Policy environment

Agriculture and rural development policies pursued by succeeding governments in Ethiopia have been among the major factors that created disincentives for the adoption of land conserving agricultural practices by limiting farmers' planning horizons to the short-term. Policies related to the land resource, the most important production asset for the vast majority of poor farmers and also the basis for the exercise of power and control for governments played an important role in this development. The feudal land rights system, prior to the 1974 revolution, that subjected tenants to insecure land tenure and expropriation of an important proportion of their produce and labor by the landlords, created disincentives for soil and water conservation or any land improvement. Even in the northern part of the country, where land grants were in principle hereditary, patterns of secession, inheritance and naming worked against the formation of transgenerational interests in improved land management (Hoben, 1996). In addition, development of the agricultural sector in general and peasant agriculture in particular has not been given important attention because industrial development agenda dominated the country's development plan. The first two Five-Year Plans (1957-62 and 1962-67) heavily favored large-scale commercial farms and export crops while in the third Five-Year Plan (1968-1973) the focus was on high input package programs for few high potential geographical areas promising quick results (Aredo, 1990). Consequently, small-scale farmers cultivating more than 90% of the agricultural land, and the major part of the country's agricultural area with symptoms of soil degradation that were not promising quick returns, were neglected.

The 1975 land reform proclamation by the "Derg" regime, that abolished the feudal land rights system, and eliminated large holdings, landlessness, and absentee landlordism, was expected to provide incentives for investment in improved natural resource management, including soil and water conservation. However, the economic system then pursued by the government that focused on collectivization and led to nationalization of natural resources including agricultural land, coercive actions for the promotion of service and producers cooperatives, the establishment of state farms, imposition of production quotas, state intervention in pricing and marketing, frequent land redistribution, and forced villagization, resulted in the opposite outcome. These policies brought about market failures and further lessened farmers' incentives for better natural resource management by decreasing both the security of land tenure and the profitability of agricultural investment.

Since the change in the economic policy of the "Derg" regime in 1990 and the subsequent government change in 1991, the abandonment of policies of forced collectivization and government interventions in fixing production quotas and market prices, has been expected to restore incentives for improved land resource management. Furthermore, the Agricultural Development Led Industrialization (ADLI) policy adopted by the current government, that accorded the highest ever priority to peasant agriculture, has been a marked change that raised enthusiasm. However, land and other natural resources remain under state ownership, with farmers being granted only the right to usufruct, and the option of periodic land redistribution remained open. This ADLI policy has so far succeeded neither in improving agricultural production and productivity nor in overcoming the cyclical famine and starvation engendered by land degradation and drought. As a result, concerns whether this land tenure arrangement provides farmers with incentives or disincentives for improved natural resource management in general and land use in particular, are topics of heated debate among scholars and policy makers.

3.5. Soil erosion research

Scientific research undertakings in soil erosion and related problems have been few in Ethiopia. The focus of soil research activities undertaken in research institutions has been on the physical, chemical, biological and agronomic properties of soil without much reference to the effect of erosion on these properties and the threat posed on soil productivity from soil erosion. The first systematic and institutionalized research effort has been by the Soil Conservation Research Project (SCRP) initiated in 1981. The SCRP, supported by the government of Switzerland, was initiated and carried out by the Institute of Geography, University of Berne, Switzerland, in collaboration with the Ethiopian Ministry of Agriculture.

The SCRP research program started after the massive campaign of soil conservation, supported by the FFW program, was already underway. However, it was expected to generate data on the extent of the problems, to identify potential measures for improving the situation, to provide the conservation efforts with necessary basic data for proper implementation, and to evaluate their efficiency and the possibilities for improvement that help decision-makers at different levels. However, economic considerations have not played an important role in the analysis of soil erosion and conservation problems. This is because of the difficulty of quantifying and valuing many of the costs and benefits associated with soil conservation, coupled with a feeling that economic considerations are less significant than other factors in understanding and solving erosion problems (Keddeman, 1989). In the years following its establishment, the project established research sites in different parts of the highlands across the country. These include Wello (1981) in northern Ethiopia, Hararghe (1982) in eastern Ethioia, Shewa (1982) in Central Ethiopia, Gojam (1984) in Western Ethiopia, and Illubabor (1987) in Southern Ethiopia. The specific sites within the regions were selected based on their representativity for the region with regard to parameters related to soil erosion. On these SCRP sites field data on soil loss, runoff, land use, production and related parameters have been collected over the years. Although the project has been of little help for the conservation campaign already underway, it produced a wealth of information that served as a starting point for many studies in the area of soil erosion and conservation in Ethiopia, including this and other thesis works.

The field research work for this thesis was undertaken in the vicinity of one of the research sites of SCRP, Hunde-Lafto area in Hararghe, Eastern Ethiopian

Highlands. Data from the SCRP database for the Hunde-Lafto research site, and my own survey data in the immediate vicinity of the research site were used in the analysis. Hunde-Lafto is located at about 350 km east of the capital city of Ethiopia, Addis-Abeba, and 20 km north of the zonal (District) Town of Chiro, along the main road to Harar and Dire-Dawa. The area has an altitude range of 1965 – 2321 meters above sea level. The area has a bimodal rainfall distribution, with a light secondary rainy season from March–May and a heavy primary rainy season from July–September. The most important soils in the area, in terms of coverage of arable land, are vertisols, cambisols, and fluvisols, with vertisols covering the largest part of the area (Bono & Seiler, 1983). Agriculture in the area is characterized by a small-scale subsistence mixed farming-systems, with livestock production as an integral part. Sorghum-Maize-Haricot beans (S-M-H) intercropping, typical in the Eastern Ethiopian Highlands, dominates the cropping system. The S-M-H intercropping represented more than 70% of the annually cropped area and the three crops give a higher yield when intercropped than in sole cropping under the existing practices (Schlafli, 1985).

4. Review of literature on economics of soil and water conservation

4.1. Background

Economics of soil and water conservation received little attention in the earlier literature in agricultural economics. The advancement in technological progress and the development of cheap sources of inorganic sources of nutrients for plants made soil resources of little consequence for agricultural production, at least in the United States, where most of the studies were undertaken. In addition, the influence of the 'soil and water conservation fundamentalism' philosophy, arguing that soil is a basic resource, that all life, including human survival and development, depends upon, and thus conserving soil is worth whatever it costs, might have contributed to the serious neglect of estimating costs and benefits of soil and water conservation (Seckler, 1987). However, concerns about further expansion of agricultural output causing substantial increases in soil erosion, rising energy costs, and externalities arising due to soil erosion, such as reservoir sedimentation, water and air pollution, stimulated studies in the area of soil and water conservation (Burt, 1981; McConnell, 1983).

The purpose of soil conservation is not merely to preserve the soil but to maintain its productive capacity while using it (Troeh *et al.*, 1999). Therefore, decisions on conserving soil erosion and rehabilitating degraded land depend on the costs relative to the value of output or environmental benefit expected. Since the value of fertile soil is not infinite relative to other human needs, it is not worth preventing soil erosion unless the benefits gained exceed the costs incurred in conservation activities (Barbier & Bishop, 1995). Therefore, farmers will not be interested in investing in conservation and bearing associated risks unless they perceive a significant threat posed on productivity due to soil erosion and expect economic gains from conservation practices. Not only economic return or profit considerations but also other socio-economic circumstances of individual farm households, and risk considerations, may play a significant role in soil and water conservation decisions.

The literature on economic analysis of soil and water conservation (SWC) can be broadly divided into three main categories. The first category includes studies aimed at establishing a relationship between soil erosion, crop productivity and farm income, and estimation of benefits from soil and water conservation. The second category includes those studies focused on behavioral issues, assessment of empirical evidence on a range of agro-ecological and socio-economic factors influencing farmers' SWC decision behavior. The third category includes studies dealing with the development and application of economic modeling tools to identify the trade-offs in favor of, or against, SWC decisions.

4.2. Erosion effects on productivity and income

The basic concern with erosion, from an individual farmer's economic point of view, lies with its effect on actual and potential productivity of land and hence on farm income. However, quantifying the effect of soil erosion on crop yield is a complex task because it involves the assessment of a series of interactions among soil properties, crop characteristics, the prevailing climate, as well as management systems (Stocking, 1987; Lal, 1988; Lal & Okigob, 1990; Clark, 1996). The task of establishing the relationship between soil erosion and productivity is further complicated by the fact that technological advances, such as irrigation, fertilization and improved crop varieties, have masked the cumulative effect of erosion on production (Enters, 1998a). In addition, Stocking (1987) argued that productivity and erosion are not independent, and do not change discretely in isolation of other factors, and that erosion rates are poor indicators of loss in productivity. However, the task of estimating the relationship is important in order to obtain an estimate of the magnitude of the effect in terms of monetary units so that information can be provided to planners and policymakers. It also provides the important link between the physical, chemical, biophysical, and agronomic aspects of soil erosion and the economic aspect.

Empirical models ranging from simple to complex have been used to estimate the effects of erosion on crop yield (Clark, 1996). Lal (1988) argued that the most relevant approach to determine erosion-caused reduction in soil productivity is the direct agronomic approach that relies on the estimation of crop yields on land from which the loss of surface soil has been recorded directly on field runoff plots. Evaluation of yield records from long-term agronomic experiments over the same soil under different management can provide an indirect measure of changes in productivity due to changes in soil property under the different management systems, such as conservation and no-conservation. Under African conditions, Lal (1988) established a relationship between soil loss and crop yield based on long-term experiments on field run-off plots in Nigeria. He found that yields of maize and cowpeas have an exponentially declining functional relationship with the topsoil loss. Bishop & Allen (1989) and Bishop (1995) also adopted this relationship for studies in Mali and Malawi. Ekbom (1995) also suggested nonlinear relationship between productivity loss in percent and soil depth loss in Kenya.

The quantification of the effect of soil loss on crop yield has laid the grounds for valuation of costs of erosion as well as estimation of benefits from soil and water conservation efforts. However, most of the empirical studies in this category of literature focused on the analysis of the on-site effect due to the farm level perspective of the studies and also due to difficulties of getting reliable information on off-farm effects. This focus is justified by the assumption that there is no private economic incentive for farmers to pay attention to the off-farm effects. Among the different techniques used to evaluate the on-site economic costs and benefits of soil erosion and conservation are hedonic pricing, change in productivity, and replacement cost (Bishop, 1995; Clark, 1996; Enters, 1998a).

Hedonic pricing has been used to value soil degradation due to erosion by considering sale prices and/or rental charges of plots that differ only in the extent of physical degradation. The application of this technique is limited in many developing countries where land markets do not exist or are poorly developed, and property rights are poorly defined. Furthermore, studies cited by Bishop (1995) suggest that soil degradation is not automatically reflected in land prices even where markets are relatively well developed, due to lack of information on the extent of erosion and its effect on productivity, and to the masking effect of exogenous technical improvements.

The replacement cost approach is based on the estimation of the cost of additional inputs, usually fertilizer cost, required to compensate for reduced soil fertility due to erosion. According to Bishop (1995), Clark (1996), and other different sources cited by Enters (1998a) this approach is appealing and relatively simple but misleading due to various reasons. The shortcomings summarized by Enters (1998a) suggest that (a) there is absence of well established links between loss of nutrients and loss of production, (b) soil erosion affects not only the nutrient status but also its organic matter content and physical structures, (c) soil nutrients may not be the most limiting factor in crop production, (d) fertilizer application may not necessarily be the cost effective option, and (e) soil erosion affects not only nutrients in plant available form that can be compensated by artificial fertilizer application but also affects fixed elements.

The change in productivity approach relies on empirical estimates of the impact of erosion on crop or livestock yields. It takes into account both the direct effects of soil erosion on crop productivity due to soil being washed away or crops being buried, as well as indirect effects due to changes in soil property. Erosion damage is equated with the value of the lost crop or livestock production value in market prices. This approach is the most frequently used (Enters, 1998a) and intuitively the most appealing (Bishop, 1995) method for valuing on-site costs in terms of foregone revenues due to loss of soil or reduced soil depth.

In addition to the valuation of the economic impact of soil erosion, studies were also extended onto the analysis of the benefits of SWC. Benefits from conservation are found in the difference in the value of production from plots with and without SWC treatment, net of the cost of conservation. The most commonly used method to evaluate the on-site economic benefit of SWC is the cost-benefit analysis (CBA), and the discounted net present value (NPV) of returns is the commonly employed decision criterion. The application of CBA to valuation of natural resources and environmental projects has got limitations that, under certain circumstances, might be serious enough to mislead policy decisions (Chichilnsky, 1997). Bojö (1992) discussed the most frequent arguments against the use of CBA as it applies to SWC projects. These opposing arguments suggest that (a) monetary measures are unethical, (b) CBA overemphasizes the quantifiable, (c) aggregation value over individuals serves to hide conflicts, (d) there is a problem of the price to be used, (e) results can be manipulated to cover for vested interests and, (f) it incorrectly assumes rational use of economic results for decision-making. However, based on a review of 20 empirical studies from developing countries with an explicit component of SWC, Bojö (1992) concluded that regardless of some limits to the full application of CBA its careful application might still improve decision-making in SWC. Many other authors in the field share this opinion (Blaikie, 1987; Ekbom, 1995; Clark, 1996; Enters, 1998a, b). De Graaff (1996) also argued that in developing countries, where capital and skills are scarce and increasing current income has high priority, efficiency is still the major criterion and CBA is the dominant evaluation method.

4.3. Decision behavior analysis

For decades it has been believed that technological innovations combined with scientific methods were the answer to erosion problems. As discussed by Lovejoy and Napier (1986), conservation problems, like other social concerns, have frequently been approached from the perspective of a technological fix, based on the position that technology will generate solutions for all and any problems. However, regardless of advances in the development and promotion of technologies, the soil erosion problem persisted, forcing changes in attitudes to the way to tackle the problem (*ibid.*). This led to the realization that soil conservation is not only a technical problem but also a socio-economic problem, which directed attention to socio-economic and behavioral factors influencing soil conservation decision-making. This shift in focus is evident from the ever-increasing literature on factors affecting adoption of SWC technology in recent decades.

The literature on farmers' SWC decision behavior succeeded in highlighting the complexity of factors involved, and each study further adds to the body of knowledge in the area by identifying new variables to be considered in the behavioral function. The complexity arises from the location-specific nature of the problem and the diversity of farmers' circumstances that make it difficult to draw some reasonable generalization. These differences spring from the variation in agro-ecological, socio-economic and institutional factors among countries, regions, villages, farms, and even plots. The most commonly used econometric models in adoption studies are the limited dependent variable models such as logit and probit. For this purpose, both probit and logit analyses are well-established approaches in studies focusing on the adoption of technology (Burton *etal.*, 1999). The choice of whether to use a probit or logit model, both widely used in economics, is a matter of computational convenience (Greene, 1997). The main assumption underlying such discrete choice theory is that consumers rationally choose from a number of alternatives and pick the one that yields the highest utility level. Unlike consumer theory, where a demand function can be driven from a utility maximization problem, discrete choice theory implies working directly with the utility function.

It is generally agreed, in SWC adoption literature, that the natural physical environment, together with social, economic and institutional factors is responsible for the SWC decision behavior both in the developed and developing world. However, the specific socio-economic and institutional variables affecting decision behavior, and hence relevant to be included in the utility function, may differ between developed and developing countries, different sites within the same region and country, as well as between different farm households and plots. Moreover, the magnitude and direction of influence of different variables vary between different types of conservation practices.

The variables most often considered in SWC adoption decisions in developed countries are erosion problem perception, age, educational status, cash crop production, income level, off-farm income, farm size, land tenure, and debt status of farmers. Studies from two different counties of the United States (Ervin & Ervin, 1982; Norris & Batie, 1987) and from Canada (Smit & Smithers, 1992) identified a range of factors affecting efforts in SWC. The significance and direction of influence of the factors in these studies are in agreement only for the positive effect of farmers' perception of the erosion problem and the negative effect of cash crop production. For the rest of the variables, the findings suggest that the magnitude, significance and direction of influence vary between countries and sites. Furthermore, Smit & Smithers (1992) showed that factors influencing different conservation practices within the same area such as conservation tillage and crop rotation also vary.

Studies undertaken in developing countries have examined the influence of variables identified in the context of developed countries and further extended the list of variables as they apply to the context of developing countries. Some of the new explanatory variables added to the list are related to the resource-poor subsistence farming nature of agriculture in these countries. These include family size, plot area, access to credit, land/labor ratio, location of plot (distance from dwellings), and cultivable land holding. These factors received consideration because the high cost of establishment and maintenance of conservation structures and the area of land lost to conservation structures often served as a disincentive for adoption of SWC structures by resource-poor farmers in developing countries, operating at the margin of survival.

Research findings that can give an overview of the factors influencing SWC decision in developing countries include studies from Philippines (Pandey & Lapar, 1998; Cramb & Nelson, 1998; Lapar & Pandey, 1999), India (Pender & Kerr, 1998), and Ethiopia (Shiferaw & Holden, 1998). As reported in these studies, the educational status of household head, slope of a plot, and plot area generally influence conservation decisions positively, whereas age of household head and distance of plot from dwelling affect conservation decision negatively. Pender and Kerr (1998) and Pandey & Lapar (1998) have also shown that the importance and direction of influence of different variables vary among different sites in the same country or region.

One of the most debated factors, whether it has significant influence on SWC decision or not, is the land tenure system. Some studies specifically tried to look into this issue. The results are, however, inconclusive owing to differences in land tenure arrangements and variations in the reaction of farmers due to differences in the agro-ecological and socio-economic conditions under which they operate. Some suggested that land tenure has a significant influence on SWC decision behavior, and others demonstrated that it has no significant influence. These include studies from the United States (Lee, 1980), Thailand (Feder & Onchan, 1987), China (Li *et al.*, 1998), Burkina Faso (Brasselle *et al.*, 2002) and Ethiopia (Benin & Pender, 2001). A summary account on different other preceding research results in Africa provided in Brasselle *et al.* (2002) clearly demonstrates the variations in findings, and hence the difficulties for generalization beyond the specific settings under which the studies were conducted. Another, somewhat different approach in the behavioral analysis is presented in *ex-ante* analysis of farmers preferences (Napier and Napier, 1991; Schnitkey *et al.*, 1992; Carter *and* Batte, 1993; Pompelli *et al.*, 1997; Tucker *and* Napier, 2002). These studies dealt with the analysis of farmers' preference for sources of information and communication channel concerning SWC techniques. Findings in this area suggest that farmer preferences for type and source of information regarding SWC techniques and methods is also a function of farm and farmer characteristics.

4.4. Dynamic economic modeling

Soil management is a dynamic process that must be adjusted continuously to changes in soil depth. Farm production and income may increase, within limits imposed by technology, by the use of depletive and intensive agricultural practices in the short-term. However, the resulting soil loss and, consequently, soil stock depletion, results in diminishing soil productivity and, therefore, losses in farm income and profitability in the long run. Effects of soil erosion on crop yield, and consequently on farm household income, are dynamic in nature, in the sense that the current year's soil loss will affect not only the current year's yield level but also the yield level of succeeding years. Similarly, the effect of investment in soil and water conservation (SWC) on crop yield and farmers' income is also dynamic in nature because soil conserved today will help to improve crop yield and farm income in the future. This nature of the subject suggests the need to consider the economic implication of soil and water conservation investment from the long–term intertemporal perspective as well.

Dynamic economic modeling technique emerged in the literature of economic analysis of SWC in the early 1980s with the work of Burt (1981). This progress in the method of analysis is appealing because decisions on soil management affect not only the income and well-being of the present but also that of the future generation. The major contribution of this approach has been to single out the impact of specific factors, such as price and discount factors, on SWC decisions for a profit-maximizing farmer, and also demonstrates the rationale of farmer decisions in tolerating a certain amount of erosion. Results in literature of this category are also often inconclusive about the direction of influence of the specific factors considered, especially market prices.

Burt (1981) applied a dynamic optimization model in the economics of soil and water conservation studies using data from the Palouse area of the Northwestern United States. He used two state variables, topsoil depth and percentage of organic matter in the topsoil. The percentage of land under wheat, that is expected to affect soil depth and organic matter content, is used as decision variable. The evaluation criterion was the maximum present value of net returns from the land resource over an infinite planning horizon. He assumed that the market for land would reflect the implicit value associated with various levels of the state variables, in case the farmers' planning horizon is finite. The results of his analysis suggested that relatively high grain prices exacerbate soil erosion problems. However, loss of topsoil and organic matter due to erosion was reported not to be serious threat on future productivity of the soil because it is more than compensated by technological progress. Regardless of its pioneering contribution, in the application of a dynamic optimization model in decisions on soil and water conservation, Brut's analysis was criticized and its results were questioned on the basis that he did not include promising conservation tillage or structural alternatives for erosion control as a decision variable (Taylor *et al.*, 1986).

The other more influential model in the area of SWC is the one developed by McConnell (1983). That is a simple theoretical model of optimal control theory that helps to determine the optimal intertemporal path of soil use. Soil depth is considered as the state variable, and soil loss as a decision variable. He argued that soil is an asset that must earn a rate of return equal to returns on other assets. The return to a farmer obtained from soil is characterized by two elements. The first comprises the value of soil as an input to agricultural production in both the current and future periods, which thus contributes to profit. Secondly, the amount and productivity of the soil at the end of the planning period will affect the potential resale value of the farmers' land, reflecting the capital element. The optimality condition for a profit-maximizing farmer to tolerate soil erosion is to use the soil up to the point at which the value of its marginal product equals its marginal cost. The value of the marginal product is the additional current profit while the cost is the foregone future profit from depleting the soil in the current period plus the capital loss at the end of the planning period. This implies that any change that would increase the cost of soil loss or decrease the benefit would lead to reduction in soil loss, and vice-versa. Hence a decrease in the farmers' discount rate or an increase in future prices, for example, will reduce the optimal rate of soil loss. Similarly, a temporary increase in current prices or increase in the discount rate will result in a greater soil loss.

According to McConnell, if the capital market works efficiently and the private and social discount rates are equal, then the private and social objective functions in agriculture will be the same. Under this condition, the private intertemporal path of soil use will converge to that of society, and hence on-site productivity losses are unlikely to be excessive. As discussed earlier, there are causes for imperfections in market and even nonexistence of some markets, and that the social rates of discount will not equal private rates in most developing countries, making the conclusions inapplicable. Even if perfect markets exist, the private and social rates of soil erosion are likely to diverge (Kiker & Lynne, 1986). The use of land resale value in the model also makes it difficult for use in the context of developing countries due to the prevailing land tenure arrangements and general lack of presumed efficiency of a private market in agricultural land. Another critique of McConnell's work is based on his assumption that the exogenously determined product prices, input costs, the land resale value function, as well as the discount rate over an infinite time horizon are known to the farmer with certainty (Kiker & Lynne, 1986).

Other authors (Barrett, 1991; Clarke, 1992; LaFrance, 1992; Hu *et al.*, 1997) used McConnell's model as a starting point in efforts to model farmers' SWC decisions in developing countries. However, the issues of land resale value are often typically removed from the maximization problem and replaced by the planning horizon extended towards infinity. They applied the model to determine whether a change in the output or the input price may affect soil and water conservation decisions of farmers. The effect of prices on soil loss has been given considerable attention because of the conventional wisdom among many agricultural economists that when product prices rise, or farmers benefit from subsidies directed towards inputs, agricultural land will tend to be used more intensively, leading to lower equilibrium land quality or, equivalently, to more degraded land (Clarke, 1992). It is an effort to advance environmental arguments alongside standard economic efficiency arguments for the elimination of price supports that are argued to have exacerbated soil erosion.

In the model by Barrett (1991), soil depth is considered as a state variable and soil loss due to cultivation as a decision variable. LaFrance (1992) used two decision variables, cultivation and soil conservation. Barrett's results did not show that changes in output or input prices have a direct effect on SWC decisions. He, however, argued that indirect effects are possible. If soil conservation appears to be more attractive than the use of more non-soil inputs, then the price change may encourage soil conservation by inducing farmers to use more of the non-soil inputs. LaFrance demonstrated that direct subsidies or taxes on conservation, such as per unit tax on soil loss or a per unit subsidy on soil growth, and reduction in real discount rate provide better incentives and are more effective to encourage investment in SWC than input and product price subsidies or taxes. However, he noted that subsidies on commodity prices might not always have a negative effect on the soil stock because the soil may be improved or further degraded.

Clarke (1992) also obtained results contradicting the assumption that higher output prices impose greater pressure on the use of farm soil and hence resulting in increased equilibrium land degradation. He argued that land use decisions by rational farmers would not be taken independently of soil conservation measures and their associated costs. Farmers in this situation face an intertemporal choice regarding the use of their farm. Therefore, supply decisions will not be related to current output prices independently of land-investment decisions. The decision depends both on current and future output prices. He showed that the effect of price change on land degradation depends on the existence of viable soil conservation technology as well as the complementarity/substitutability relationship between inputs. When farmers have viable soil conservation technology to offset the effects of land degradation, they respond to favorable price movements by increasing their sustained investment in soil quality and thereby reducing the extent of land degradation. However, when farmers do not possess viable soil conservation technologies, and mine soils as non-renewable resources, either type of favorable price movement leads to lower equilibrium level of soil quality. Hu *et al.* (1997) extended McConnel's model and applied to the management of wind erosion on rangelands with two state variables, "grass stock" and "soil stock", and one control variable, "animal stocking rate".

5. Summary of articles

5.1. Introduction

In this section summaries are given of the purpose, theoretical model, empirical analyses and major findings of the four articles comprising this thesis. Private economic returns from investment in soil and water conservation (SWC) to subsistence farmers are analyzed in articles I and II from the temporal and intertemporal perspectives, respectively. Financial returns might not be the only, or even the major, consideration that provides incentive to subsistence farmers for investment in soil and water conservation. Socio-economic and institutional factors operating from the level of the national economy through the individual farm household all play a strong role in shaping farmers' incentives for SWC investment. At the basis of the individual farm households that take the ultimate decision on the way the agricultural land is to be used, in ways that lead to erosion or conservation. Factors operating at the higher level in the hierarchy of decision-making play a role in influencing farm level actions by providing incentive or disincentive for one or other type of land use. Therefore, the effect of agro-ecological, socio-economic and institutional factors on SWC decisions is analyzed in article III. Generally farmers have different problems, resource endowments, and socio-economic background. Based on these differences their strategies for resource allocation could be different. Considering these differences may help to design development policies and strategies best suited for different situations. Article IV, therefore, considers the broader context of subsistence farmers' agricultural production problems, including soil erosion, and elicits the priority ranking of these problems in the determination of farmers' preferences for development intervention. The priority rank of agricultural problems together with other socio-economic characteristics of the farm households are then analyzed for their influence on farmers' preferences for development intervention.

The underlying assumption in all of the articles is that individual farm households act rationally and allocate resources in accordance with their farm income and utility maximization objective, given their resource endowment and constraints. Soil erosion, and hence soil and water conservation decisions, have both on-site and off-site effects. This requires approaching the problem of soil erosion both from the individual and social economic perspectives. From the social economic perspective all costs and benefits, on-site and off-site, need to be accounted for with the objective of maximizing welfare from soil use while maintaining its productive potential into the future. From the individual’s perspective, however, only the direct on-site costs and benefits are of interest because there is generally a lack of incentive to take into account the external costs and benefits. Due to the orientation of this study on individual farm households, only the on-site costs and benefits are considered in the analysis. On-site benefits to farmers may not be the largest benefit of soil conservation. However, given the farm level perspective of the study and the central role of farmers in soil conservation decisions, on-site benefits are likely to be the most crucial, especially in less developed countries (Pattanayak, 1998).

5.2. Article I - Stochastic dominance analysis

The aim of this article is to analyze whether investment in soil and water conservation results in a higher yield and return, and/or mitigates variability in yield and return to subsistence farm households in the study area. In order for farmers to invest in SWC measures and retain the practice as an integral part of their farming practices, they need to have incentives in terms of improved yield and returns and/or reduced variability. When the conservation practice is unprofitable in terms of improving expected yield and return and/or reducing variability, the probability of investment and maintenance of the practice by farmers will be low. As pointed out by Shively (1999), understanding the impact of SWC on yield risk is important for two reasons. Firstly, SWC measures are widely promoted for use by low-income farmers, many of whom have limited opportunities to reduce their exposure to risk. Secondly, production risks influence the incentive to adopt the practice, and an understanding of that may help to explain the patterns of adoption.

Yields and net returns from a traditional crop production system without SWC structure and a practice that involves the construction of soil/stone bund type of physical SWC structures were compared based on stochastic dominance (SD) criteria. A comparison based on returns net of conservation cost is used in the analysis because comparisons based entirely on yield may be biased in favor of an alternative that results in higher yield but also displays higher cost. Constant grain price and wage rate are used in the analysis in order to determine only the stochastic outcomes. SD criteria help to make pair-wise comparisons of a set of alternatives based on cumulative probability distributions. In order to determine whether investment in SWC unambiguously results in higher yield and return than without conservation farming practice, a nonparametric first order SD analysis is undertaken. For determination of whether agricultural practices that involve SWC unambiguously reduce yield and income variability to subsistence farmers, as compared with practices without conservation, a normalized second order SD approach was used. The empirical analysis is based on the Soil Conservation Research Program (SCRP) database for the Hunde-Lafto research unit (SCRP, 1996).

First order SD and second order SD analysis basically differ in their capacity to rank alternative choices and the nature of assumptions required. The underlying assumption in first order SD is that farmers maximize expected utility. That means that the first order stochastically dominant alternative will be chosen by farmers who always prefer higher expected returns to lower. This assumption describes large groups of subsistence farmers. Second order stochastically dominant strategy will be chosen by those farmers who prefer higher returns to lower, and are also risk averse (Oriade *et al.*, 1999). The assumptions associated with this criterion are monotonocity and concavity of the utility function (Post, 2002).

The results of first order stochastic dominance analysis showed that expected yield and return from crop production with soil and water conservation unambiguously dominates the yield and returns without conservation. Due to the subsistence nature of agriculture in the study area, where production is mainly for home consumption and sale of crops is often limited, quantity of food crop production is of major concern to households. This result, therefore, suggests that soil and water conservation is a dominant production strategy for farmers when improving yields and increasing food crop availability is a major concern. The results of the normalized second order stochastic dominance analysis do not support the hypothesis that soil and water conservation strategy unambiguously results in less yield and return variability than no-conservation strategy. However, the conservation strategy still remains dominat under low yield and return levels that often correspond to unfavorable rainfall conditions. As shortage of rainfall is an important risk factor that results in frequent crop failures in the country, it can generally be concluded that conservation is a dominant strategy for subsistence farmers in the study area.

5.3. Article II - Optimal path of investment in soil and water conservation

Soil management is a dynamic process that must be adjusted continuously to changes in soil depth. The dynamic nature of the effect of soil loss, and consequently of soil conservation, on productivity and income necessitates intertemporal analysis of the subject. A mathematical method often used to develop optimal strategies for soil resource use over time is a dynamic optimization model. The major contribution of this method has been to single out the impacts of specific factors, such as price and discount factors, on SWC decision for a profit-maximizing farmer, and also demonstrates the rational of a farmer's decision to tolerate a certain amount of erosion (Eaton, 1996). This study applied a dynamic programming model to determine the optimal time path for investment in SWC by subsistence farmers in the study area. In a dynamic programming model primary attention is focused on the optimal value of the function rather than on the properties of the optimal control path as in the optimal control theory (Chang, 1992). This makes dynamic programming more appropriate and flexible for empirical application. It also has an advantage in that it can be used to obtain numerical solutions to problems that are analytically intractable (Kennedy, 1986).

In the dynamic programming model soil depth was used as a state variable, and soil and water conservation decision (amount of soil depleted) is used as control variable. Three levels of the decision variable, corresponding to recommended type of SWC, modified type of SWC, and no SWC were considered in the analysis. Seven decision stages, each being a progression of five production years, spanning a planning horizon of 35 years, were considered in the analysis. The optimal decision rule for a given stage is the highest cumulative present value of returns, net of conservation cost, from that stage to the last stage plus the terminal value; the optimal policy being the optimal decision rule for the first stage. In order to overcome the problem of absence of market for land to value the land at the terminal period, an estimated value of the productive potential of the remaining soil depth is used as a proxy for the terminal value.

Data from the Soil Conservation Research Program (SCRP) database for the Hunde-Lafto research unit (SCRP, 1996) was used. The analysis was made using the General Purpose Dynamic Programming (GPDP) software developed by Kennedy (1986). Analysis was made for different price levels and discount rates to single out the impacts their impacts on the optimal path, as part of a sensitivity analysis. Results of the analysis show that an increase in the discount rate creates disincentive for investment in soil and water conservation. This indicates that farmers' time preferences will affect their conservation decisions. Increase in the market price of grains was found to provide incentive for investment in SWC, whereas lower prices discourage investment. Lower market prices result in lower return from production that would be offset by the higher cost of establishment and maintenance of conservation structures and area of land lost to conservation structures. Further analysis of the results suggest that agricultural practices without SWC yield higher returns per period in the short-term, while practices with SWC yield higher return per period in the long-term as well as a higher overall return. The present value of returns from soil and water conservation increase with an increase in targeted levels of effort in soil and water conservation. The relationship, however, exhibits a diminishing marginal increase in returns as the targeted level of effort in conservation increases. Development policies, aimed at promoting SWC, therefore, need to provide incentives for farmers so that they will forgo higher returns in the short-term and distribute soil use over longer periods to ensure the higher long-term and over-all returns.

5.4. Article III – Soil and water conservation decision behavior

It is difficult to generalize about the factors affecting adoption of SWC technologies in different parts of the world or even in different regions of a country because of differences in agro-ecological and socio-economic settings under which farmers operate. Whereas the principal economic rationality assumption, the utility maximizing objective of individual farmers, might be the same for farmers everywhere, the specific attributes influencing the utility of farmers and adoption decisions are far from being uniform. Adoption of soil and water conservation practices depends upon these differences in attributes, many of which are specific to a particular region, village, farm, or plot. The purpose of this study was to analyze plot-level determinants of soil and water conservation decisions by subsistence farmers in the study area.

Subsistence farm households in Ethiopia in general and in the study area in particular usually manage and use more than one plot located at different sites. Plots are spatially distributed across different slope classes, soil types and distance from residences. They may also differ in soil type and suitability for a particular crop. Owning plots distributed spatially is among the important strategies of farmers to reduce exposure to risk. As a result, farm households may have different soil and water conservation decisions for different plots depending on the specific circumstances of a plot and the importance of the plot to the household economy. This makes the analysis at plot level more appropriate and informative than analysis at farm or household levels.

Limited dependent variable models, such as logit and probit, are well-established models often used in adoption behavior studies. Because an adoption decision by farmers is inherently a multivariate decision, attempting bivariate modelling excludes useful economic information contained in the interdependent and simultaneous adoption decisions (Dorfman, 1996). This makes the use of a multiple-choice decision model more appropriate. Hence, the multinomial logit model was chosen for this study. This model makes possible the determination of factors influencing soil and water conservation decisions in the context of individually specific data on multiple choices. In the multinomial logit analysis, plots were classified according to their status at the time of the survey, and the distribution of plots among groups was explained in terms of the characteristics of the plot and the farm household.

Data were collected from 145 randomly selected farm households, managing 265 plots in the study area through individual interviews using semi-structured questionnaires. Prior to the formal survey an informal survey was conducted using individual interviews and group discussions with farmers and key informants. The information collected in the informal survey helped to guide the development of the formal questionnaire. The questionnaire was pre-tested in training enumerators who were to help me conduct the interviews. Based on the formal survey result, plots were grouped into five based on their status at the time of the survey: (1) plots from which conservation structures built through project assistance were removed; (2) plots that never have had a conservation structure built; (3) plots with traditional soil conservation structures; (4) plots with farmers' modified types of conservation structures, and; (5) plots with recommended type of conservation structure. A list of plots and farm-specific variables with potential to influence soil and water conservation decisions was used in the analysis.

Results of the multinomial logit analysis suggest that the adoption of each class of conservation structure is influenced by different factors and at different levels of significance by the same factor. For instance, the adoption of traditional and modified structures that may have been classified as one group together with non-adopters in a binary choice model are shown to be influenced by different factors and at different levels of significance by the same factor. The same can be said of the adoption of recommended and modified types of structures. In general, plot area and slope, access to information, and project assistance have shown significant positive correlation with SWC decisions. Family size and land holdings per economically active household member are found to negatively influence the decision. In promoting soil and water conservation technologies to farmers, attention needs to be paid to the agro-ecological variations of the farming environment, and socio-economic characteristics of the target groups.

5.5. Article IV: Farmer preferences for development intervention

Most studies dealing with the impact of rural development programs and adoption of agricultural technology by farmers in developing countries are often based on *ex-post* analysis of intervention programs. Farmers are rarely consulted *a priori* about their specific circumstances, priority problems, and their preference for certain types of intervention. The adoption behavior study often comes after the costs are incurred and the technologies have been diffused. Farmer's preferences for the type of intervention rarely appear in the long list of explanatory variables suggested. Such technological interventions often resulted in low level of acceptance by the target group and resulted in a lower level of success for development programs (Feder *et al.*, 1981). Prior identification of farmers' priority problems and predisposition with respect to the usefulness of a development interventions program may help to gear development intervention programs to the needs of different regions and group of farmers. This helps to design more acceptable and cost effective development programs.

This paper provides insight into this aspect of rural development issues by eliciting farmer-felt priority problems and preferences for development intervention. Having identified farmers' preferences for intervention, the agricultural problems and socio-economic factors assumed to determine the preferences were analyzed. The underlying assumption in this study was that farmers, based on their extensive knowledge of the farming environment and the outstanding agricultural problems, can state their preference for development intervention (PDI) in line with their utility maximization objective, given their constraints and resource endowments.

Data for this study were generated in parallel with the SWC decision behavior study survey conducted in the summer of 2000 in the study area. A total of 145 farm households were randomly selected and individually interviewed using semi-structured questionnaires. The econometric model used to determine factors influencing farmers' preferences for development intervention is the random utility model (RUM) that provides the link between a statistical model of observed data and an economic model of utility maximization. Under the assumption that error terms in the RUM are logistically distributed, the multinomial logit model is used for data analysis.

Results of the study revealed that among numerous agricultural production problems faced by subsistence farmers, five are perceived to be the most important. These were frequent drought, soil erosion, cultivable land shortage, lack of grazing land, and crop diseases and pests. Low market prices for farm products and high prices of purchased inputs also came out as major problems for the majority of farmers. These problems identified by the sample farmers are not considered as a reevaluation because most of these problems are well known and documented agricultural problems of the country as a whole. The results of the study, however, show that farmers are not unaware of the farming problems and their priority rankings differ as a function of their resource endowments and socio-economic circumstances. Areas of preferred development intervention identified by farmers include input and output markets, soil and water conservation, irrigation development, and resettlement in productive agricultural areas. The preferences, however, are not considered to be mutually exclusive. These stated preferences of farmers, for development intervention, corresponded to past and current rural development programs pursued in the country by government and international donor organizations. This indicates the awareness of farmers about alternative public actions that would help in alleviating agricultural problems, and state their preference for a particular intervention based on their specific circumstances.

Multinomial logit analysis of factors influencing these preferences revealed that farmer's specific socio-economic circumstances and subjective ranking of agricultural problems play a major role. The magnitude and direction of influence of the explanatory variables show differences for different interventions. Preference for resettlement is positively influenced by the priority ranking of the farm land shortage problem, and the educational status of the farm household head; and it is negatively influenced by the total land holding and dependency burden on the economically active household member. Preference for intervention in irrigation development is influenced positively by the farmer's experience in use of chemical fertilizers and negatively by market prices of inputs. Preference for soil and water conservation is positively influenced by the priority ranking of the soil erosion problem and the total land holding of the farm household. It is negatively influenced by food production status of the household and market input prices. Preference for market intervention is positively influenced by the food production status of the household, priority ranking of disease and pest problems and market prices. The results also suggest complimentarity of different intervention programs that require to be addressed simultaneously in order to ensure higher return from investments. Therefore, at grassroots level implementation of development programs, factors influencing the acceptance of each type of intervention have to be identified a priori and be properly addressed if development efforts are to bring about the desired outcome.

6. Conclusions

Literature on the economics of SWC has expanded, particularly in the past few decades, and the body of knowledge in the area is increasing. The improvement of knowledge in the area further shads light on issues that require close attention and further investigation under specific settings. This is brought about by the complexity of the issues of soil erosion and conservation that are intricately linked to different physical, social, economic, institutional, and management systems. One specific nature of most studies in the area of economics of soil and water conservation is that they are location specific and could not be accurately extrapolated to different levels. This thesis contributes to the body of literature in the field, and the specific results also help in assisting SWC policy decisions and identifying potential future research areas in Ethiopia.

6. 1. Contributions of the thesis

Article I contributes to the body of literature dealing with erosion, productivity and income relationship by introducing in the analysis the effect of SWC in reducing yield and income variability. From research and development policy perspectives, the results suggest the need for considering, in the design and implementation of conservation technologies, the effect of SWC structures in reducing farmers' exposure to risk due to yield and income variability. In the literature of this category, utmost focus is placed on the yield and income reducing impact of soil erosion and on the yield and income improving effect of SWC. Studies on impact of SWC in reducing variability in yield and income, and hence the farmer's exposure to risk, particularly in developing countries, are scanty. This is driven by the assumption of profit maximizing rational farmers behavior underlying most of the analyses undertaken in industrialized countries. In the context of subsistence farmers in developing countries, however, profit maximization may not be the only, or even the most important, driving force that determines a farmer's land use decision behavior. Furthermore SWC is aimed not only at improving yield and income, but also to mitigate yield and income variability, due to its capacity to retain water that would otherwise be lost to run-off and to make it available for plant growth and development. For resource poor farmers, whose agricultural production is limited to hand-to-mouth, reducing exposure to risk due to yield and income variability is an equally important incentive that influences investment decisions. Furthermore, uncertainties about returns, the appropriate type of SWC practice, and the optimal level of investment in SWC introduce elements of risk that result in market failure and curtail investment.

In the category of literature dealing with economic modeling of soil erosion and conservation, the noticeable gap is that there exists little or no empirical work in the context of developing countries. Furthermore, the common assumptions about the existence of a competitive market and resale value of land make its applicability for subsistence agriculture in developing countries very limited, particularly where land is not a tradable commodity and the capital market is poorly developed. The attention of many studies applying optimal control theory is focused on the properties of the optimal control path rather than on the optimal value of the function. As a result, the findings were of little practical guide in policy decision-making in developing countries as to the alternative type of practice to promote and support. Article II, therefore, contributes to the body of literature in this area through empirical application of a dynamic programming model that places focus on the optimal value of the function and is more flexible for empirical application. The specific results showing the effect of grain prices and discount rate help to guide policy-makers to weigh different alternatives to provide incentives for conservation investment. It was shown that soil erosive agricultural practices generate higher return than soil conserving practices in the short-term. As a result, private economic incentives to invest in long-term land improving practices, such as soil and water conservation, will be weak, particularly when there is market failure. This draws attention to a need for the design of incentive mechanisms to extend a farmer's planning horizon to the long-term, whereby current benefit can be forgone in favor of realizing overall long-term income and environmental benefits.

An important lesson from articles III and IV concerns the importance of accounting for differences in agro-ecological and socio-economic circumstances of farmers in the design and implementation of rural development programs in general and soil and water conservation projects in particular. These articles contribute to the category of literature addressing farmers' SWC decision behavior in developing countries in two important ways. Firstly, unlike most previous studies where SWC technology adoption decision is treated as a binary choice process, whether a farmer adopted a recommended type of SWC technology or not, a multiple choice decision model was applied in this study. In developing countries, the problems farmers face are more complex and require face multiple-choice decisions. In the simple adopter and non-adopter binary categorization, the adoption of other alternative measures, such as traditional and modified types of conservation practices, is often undermined. Results of the analysis have shown that adoption of traditional and modified structures that may have been classified as one group together with non-adopters in a binary choice decision model are influenced by different factors and at different levels of significance by the same factor.

Another equally important issue, left out by literature on the adoption behavior of farmers, is the influence of farmers' preference for rural development intervention in general and SWC in particular. Farmers' preferences for intervention in the area of SWC in general, and specific type of conservation measures in particular, almost never appeared in the list of explanatory variables that have been identified to explain adoption behavior. Farmer preference for intervention is based on the subjective ranking of agricultural problems and utility maximization objectives, given the constraint imposed by limited resources at farmers' disposal. These preferences, in turn, influence their investment decisions in any particular technology, and hence need to be understood and be taken into consideration. Article IV addressed this issue by eliciting farmers' preferences for development intervention and analyzing factors influencing these preferences.

6.2. Suggestions for future research and development

Due to the farmer perspective of this study and lack of information on the off-site effects, analysis is limited only to the on-site effects of soil erosion and conservation. This does not, however, imply that the off-site effects of soil erosion in Ethiopia are insignificant. Therefore, it is necessary that the research work presented in articles I and II on the on-site effects of soil erosion be extended to off-site effects as well. Ethiopia, like many other developing countries, depends heavily on in its water resource to foster economic growth and development. The country counts on the development and efficient use of its irrigation potential to improve food security, to alleviate rural poverty, as well as to promote diversification of its agricultural exports. The current and future source of power in the country is largely dependent on its capacity to develop and use its immense hydroelectric power potential. Many of these potential benefits of water resource development will be undermined and lost if soil erosion problems are not dealt with adequately.

Due to severe food shortage, malnutrition, and famine problems in Ethiopia, during the past three decades, research and development focus has been on the on-site effects of soil erosion. Although there are no quantitative studies to demonstrate the impacts, there are noticeable off-site effects of soil erosion. Many lakes that serve as potential sources of irrigation water for agriculture, drinking water supply, fishery development, recreation, and also important landmarks are under continuous threat from siltation caused by soil erosion from croplands. Water reservoirs used as a source of Ethiopia's supply of electricity power are at the verge of being out of service. As a result, frequent disruption of power and rationing of electricity have become a usual phenomenon even in the capital city, let alone in other areas where the service is poorly developed. The impact assessment and economics of the off-site effects of soil erosion remains an area that requires the attention of researchers and policy-makers in the immediate future.

The complexity imposed by the impact of agro-ecological, economic, socio-cultural and institutional factors in soil and water conservation decisions, shown in articles III and IV, necessitates further studies in specific settings. This will help to develop policies that take into account both the technical and socio-economic elements of land use systems in order to create incentives for people to participate in conservation efforts. As soil erosion research in the country is in its infancy, the extent of the effect of major factors contributing to soil erosion remains unknown. In this regard, I feel that particular attention needs to be paid to the impact of livestock on soil fertility management and land degradation in specific land use systems and in the context of various socio-economic and institutional settings. In the literature on soil erosion and conservation, reference is often made to the effect of overgrazing on soil erosion, implying negative contribution of livestock to soil fertility management. However, in the mixed farming systems in the Ethiopian highlands, livestock husbandry may contribute positively to soil fertility maintenance by transferring biomass from pasturelands to cultivated plots through night parking. In addition, the contribution of livestock as a saving asset and source of cash for immediate food shortage or other financial needs helps in smoothening consumption over time, and allows family labor to be invested in land improvement activities. Therefore, assessment of the economic impact of livestock on soil fertility management and land degradation, and hence farm productivity and income, is one potential area for research and development.

Another area for research and development in understanding specific farm circumstances is incentive mechanisms to promote afforestation in order to combat land degradation. It is generally accepted that deforestation, that exposes the soil surface to various agents of erosion, is responsible for accelerated soil erosion and land degradation problems in many developing countries, including Ethiopia. Although deforestation unquestionably contributes to land degradation, there is a general lack of quantified research information to show the magnitude of the effect in order to trigger policy interventions that foster its contribution to soil conservation and other ecological services. As a result, its contribution to the national economy is underestimated, and resource allocation for research and development in the sector is limited. The success of previous efforts in afforestation of communal lands and introduction of agro-forestry practices has been limited due to lack of knowledge of appropriate incentive mechanisms to trigger adoption by farmers. Therefore, research to evaluate the soil conserving effect and other services of forests to the household and national economy, as well as the incentive mechanisms for farmers to promote afforestation, is another area for research and development in Ethiopia.

Research and development efforts need not be limited only to already degraded agricultural lands. Protecting soil in less degraded areas from depletion due to erosion, and monitoring the impact of new settlement schemes also need consideration. As discussed in article IV, resettlement in potential agricultural areas is among farmers' preferred types of development intervention. The sustainable development and poverty reduction program of the Ethiopian government (FDRE-MoFED, 2002) also considers resettlement of people from drought-prone areas as one possible alternative strategy. Limited resettlement programs have already been started in different parts of the country. In this regard, research activities in monitoring and impact assessments of new settlements on the environment in general and on the soil resource in particular are required. Furthermore, the environmental and productivity impacts of depopulating drought-prone areas need to be followed up and studied.

Last but not least, emphasis needs to be put on the complexity of the soil erosion problem in Ethiopia and the need for multidisciplinary approaches to research and development efforts required for addressing this problem. Today, more than ever, it is understood that technical solutions alone are not a remedy for the problem of soil erosion. Socio-economic and institutional factors operating from the level of the farm through the national level also play an important role in determining the success of technical solutions. Studies in social science also strongly depend on knowledge and findings from the soil biophysical and agronomic fields. Therefore, a comprehensive solution to the problem requires intra-disciplinary and inter-disciplinary cooperation between institutions and also researchers and development workers from all fields directly or indirectly related to agriculture and soil use.

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