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Peasant Agriculture and Sustainable Land Use in Ethiopia: Economic Analyses of Constraints and Incentives for Soil Conservation

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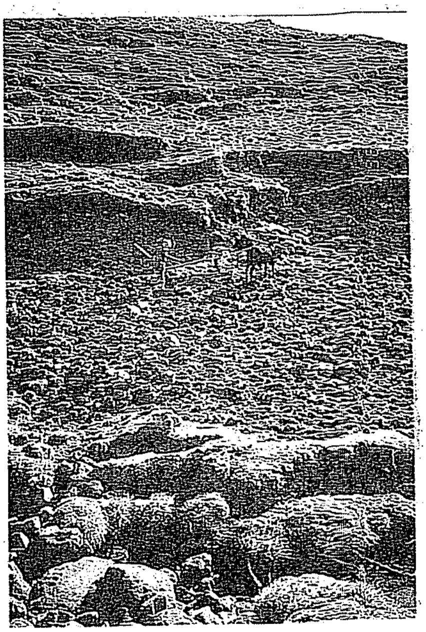
Scarcity of land and soil conservation in the Ethiopian highlands: Andit Tid

Cultivation of steep slopes: Andit Tid



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Abstract

In agriculture-based poor economies, degradation of agricultural land poses a serious threat to current and future food production potential. Ethiopia is one of the poorest countries in Africa that is heavily dependent on peasant agriculture and is affected by extensive degradation of agricultural lands. Per capita food production has severely lagged behind rates of population growth, and food shortage has become a chronic problem in the country. Coupled with the poor performance of the agricultural sector, massive poverty of the rural population, high population growth, land scarcity, technological stagnation, social conflicts, misguided policies and deficient institutional structure hinder sustainable utilization of agricultural lands. The problem of degradation of agricultural land is most notable in the highlands where human and livestock pressure is highest. This study attempts to examine the factors that deter sustainable use of land resources by peasant households, and various economic and institutional incentives that can be employed to enhance conservation-based agricultural development. Theoretical and empirical analyses of farm households' decision behavior are used to examine the constraints and incentives for sustainable land-use. Results from a farm-level optimal control model show that rural market imperfections, policy failures, and poverty may lead to disparities in the value of farmland to society and the private user even when external effects (off-site costs) are negligible. The peasant's decision to conserve or degrade land is also influenced by productivity impacts of conservation technologies, input and output prices, the discount rate, the quality of the soil, and future productivity impacts of current soil erosion.

Empirical analyses of smallholders' decisions to invest in land conservation practices using farm household data also show the importance of farmers' perceptions of soil erosion problems, perceived productivity impacts of conservation options, scarcity of agricultural land, poverty, and rural market imperfections for adoption of soil-conserving land use. Lack of awareness of erosion's productivity impacts, perceived low productivity of conservation, land scarcity, and asset poverty of the household were found to undermine adoption of conservation practices. A nonseparable farm household model developed using data from the highlands also indicate that farmers are unlikely to invest in soil conservation practices unless they anticipate a net gain in switching to a conserving-regime or unless they value forgone future benefits (user costs) from current erosion more strongly. A shift to the soil-conserving method is severely constrained when the conservation technology depresses immediate farm returns unless the on-site user costs are internalized at very low rates of discount (close to 5%). Since installation and maintenance of conservation structures is costly to the farmer, at the average estimated real rates of discount (54%), no conservation is likely to be adopted in the short-term unless soil conservation boosts yields. When farmers anticipate increased yields with conservation in the short-term, structures are likely to be widely adopted on profitability grounds even when user costs are not considered. Relaxing the fertilizer-credit constraint or increasing fertilizer prices tended to discourage conservation when conservation is yield-neutral or yield-depressing. Increases in fertilizer prices, however, crowd-out conservation quickly. When conservation is yield-enhancing, a credit constraint for fertilizer (complementary input) and a sharp increase in fertilizer prices tend to discourage conservation especially when user costs are not accounted for.

Analyses of incentives for soil conservation using a farm household approach also indicated that, in the face of a credit constraint, linking access to input subsidies or other program benefits to conservation requirements will be a useful strategy to promote conservation without serious distributional impacts on the welfare of the poor. Some of these kinds of cross-compliance incentives were found to be efficient even when conservation reduces short-term yields by 20%, and the efficiency of the incentives and the erodible area conserved increase further when conservation leaves short-term yields unaffected. Linked seed, fertilizer, and labor subsidies are found to be Pareto improving at the 10% social rate of discount, but will be inefficient at a 20% rate. Apart from linked incentives, taxing the price of an erosive crop (*teff*) was found to be more effective than supporting the prices of less erosive crops (pulses) in changing farmers' cropping pattern and hence reducing soil erosion.

Results generally indicate the need for new policies, institutional arrangements and profitable conservation technologies to encourage sustainable land use in smallholder agriculture. A closer integration of agricultural development and environmental policies, and policies for poverty reduction and rural livelihood security are urgently needed. Despite the optimism on the effect of population-induced intensification, results also indicate that land scarcity per se is insufficient to promote conservation investments unless complemented by suitable policies and enabling conditions that promote technological and institutional innovation. In view of the failure of compulsory conservation polices in the past and problems that emerge in implementing first-best price incentives to regulate soil erosion externalities, linking positive incentives to conservation requirements seems to be attractive. More research is, however, needed to study the effects of farm heterogeneity, enforcement and regulatory costs, land tenure issues, farmers' subjective rates of discount, and the productivity effects of conservation options.

Peasant Agriculture and Land Degradation in Ethiopia: Reflections on Constraints and Incentives for Soil Conservation and Food Security

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1. Introduction

Ethiopia is one of the poorest sub-Saharan countries of Africa facing severe problems of agricultural stagnation and decline, high population growth, and degradation of the natural resource base.[1] With 55 million people in 1994, Ethiopia is the second most populous nation in Africa (CSA, 1995). The population grows at a rate of 3.4% per year, which by far exceeds the rate of growth of food production (World Bank, 1992). Due to its low productivity, agriculture provides employment for about 80% of the population, but generates only 50% of the GDP. With an estimated per capita income of $100 in 1993 (World Bank, 1995), the country is one of the poorest in the world, and the extent and severity of poverty tends to be higher in rural areas. Some 60% of the population is estimated to live below the poverty line (Zegeye and Habtewold, 1995).

National statistics show that 72% of the farm households cultivate holdings less than 1 ha while the average holding is 0.8 ha (CSA, 1993). Peasant households produce over 90% of the agricultural output which accounts for 45% of the GDP, 85% of the export revenue, and some 80% of the employment (FAO, 1993). The majority of these smallholders are subsistence-oriented farm households cultivating impoverished soils on sloping and marginal lands highly susceptible to soil erosion. The peasants constitute the poorest and largest segment of the population whose livelihoods directly depend on the exploitation of natural resources. However, lack of credit facilities and policy support to peasant agriculture limit their ability to enhance productivity and undertake land-improving and conservation investments.

The pressure on the resource base is highest in the Ethiopian highlands (areas over 1500 m a.s.l.) comprising some 46% of the area of the country and covering close to half the area of the East African Highlands (Getahun, 1978). Due to relatively more fertile soils and less disease incidence, the Ethiopian highlands harbour some 88% and 75% of the human and livestock population, respectively, and constitute about 95% of the regularly cultivated lands (FAO, 1986). The Ethiopian highlands with inherently fertile soils and abundant rainfall are amongst those with highest agricultural potential in Africa, and yet they are threatened by accelerating land degradation. FAO (1986) estimated that some 50% of the highlands are significantly eroded, 25% seriously eroded, while 4% have reached a point of no economic return. The same source also estimates an average annual land productivity decline of 2.2% due to soil erosion. Estimated rates of soil erosion on croplands average 42 tons per hectare (t/ha), while rates on individual fields reach up to 300 t/ha (Hurni, 1993). Under the pressure of expanding agricultural area, demand for fuelwood and construction, and the ravages of uncontrolled forest fires, the forest area is on the verge of exhaustion as only less than 4% of the country is considered to be covered by forests. Annual forest clearance is still in excess of afforestation efforts. Apart from loss of biodiversity, the rich wildlife of the country also suffers from accelerated disappearance of their habitat.

The exploitative nature of agricultural production without sufficient use of ameliorative inputs is undermining the sustainability of the mixed crop-livestock production systems of the highlands. The scarcity of woodlands and grazing areas is forcing rural household to divert crop by-products and animal manure, traditionally used for enhancing soil fertility, for use as animal feed and firewood. Loss of soil productivity limits the ability to produce surplus for markets or meet own subsistence requirements. This is evidenced by the chronic food insecurity of the country which has suffered frequent famines since the early 1970s. Between 1979/80 and 1993/94 food production (crop and animal origin) grew annually only by a mere 0.5% (Zegeye and Habtewold, 1995), while food grain production grew by 0.44% (see Figure 1). This implies an annual per capita domestic food availability decline of 2.5% and 2.7%, respectively. Shortfalls in domestic supplies are often met through food aid and commercial imports, but this situation perpetuates aid dependence and strains the balance of payments. Poor infrastructure and marketing services and lack of credit for consumption smoothing further accentuate household food insecurity.

This paper provides a concise theoretical review of the problems and opportunities besetting the peasant agricultural sector and the intricate underlying factors behind the degradation of land, stagnation of the sector, and chronic food insecurity in Ethiopia. The focus is on the peasant mixed crop-livestock production system of the highlands, and hence no treatment of the pastoral system is given. The paper also provides a summary of the major findings of the papers that follow this introductory chapter.

2. Causes of Environmental Degradation in Ethiopia

The major environmental problem in Ethiopia today is degradation of land due to soil erosion and nutrient depletion through exploitative production (soil mining). Identification of the underlying causes of land degradation at a national level is a difficult task. Some of the issues are likely to be location specific, but some factors may be common for peasant agriculture in the highlands. The *driving force-pressure-state-response* framework is a good approach for assessment of environmental problems in the agricultural sector (Pieri *et al.*, 1995; OECD, 1996). The *driving forces* are the underlying causes that compel the land user to follow a certain agricultural practice. The *pressure* would then be the agricultural practice affecting the *state* of the natural resource base, which would in turn elicit a *response* in the form of mitigating or resource enhancing measures. The *pressure* factors (overcultivation, overgrazing, deforestation, etc.) are often blamed as the major causes of environmental degradation. Other driving forces as principal causes however, often drive these proximate causes. Resource degradation and stagnation of Ethiopian agriculture may be attributed to several factors: poverty, misguided policies and neglect of the sector, technological stagnation, population pressure, weak institutional support, insecurity of tenure, drought, and political instability (Shiferaw, 1994). Pervasive poverty in the rural areas and land degradation are closely linked factors with mutually reinforcing effects. Other factors exogenous to the peasant household regulate the poverty-environment link and determine the pathways of agricultural and environmental change. In what follows, an attempt is made to identify the major causes of environmental degradation and discuss their effects in a theoretical perspective.

2.1. Poverty-environment links in peasant agriculture

Poor rural economies in developing countries are primarily biomass-based subsistence economies (Dasgupta and Mäler, 1994) whereby the survival of millions of rural households is directly dependent on plant and animal production and/or direct exploitation of natural resources (forest, water, fish, etc.) to secure a livelihood. The dependence of poor countries on export of primary products is a reflection of their direct reliance on exploitation of exhaustible resources (soil, water, forest, fish, livestock, minerals, etc.). The degradation of these resources, therefore, impinges immediately on the livelihoods of the rural communities either through a fall in the productivity of the resources that they rely on or through adverse impacts on their health. Soil degradation, removal of land cover and overgrazing reduce the productivity of agricultural land, while water pollution through increased accumulation of soil sediments, chemicals and other contaminants may increase the incidence of water-borne diseases. The degradation of natural resources may also increase the labour time needed for household production, as in fuelwood collection or fetching water from distant locations, and compete with the labour time needed for production and conservation investments. The receding of vegetative cover and degradation of pastures may also induce diversion of animal manure and crop by-products, historically used for regenerating soil fertility, for use as vital sources of household energy and livestock feed. In the Ethiopian highlands, for example, animal manure and crop residues are increasingly used as firewood, while the latter is also becoming a major source of dry-season livestock feed. Environmental degradation may thus worsen poverty. The theses that environmental degradation could worsen poverty in fragile areas suffering from degradation of the resource base adds another dimension to the already complex challenges facing poverty alleviation and sustainable agricultural development.

Several recent studies also posit a two-way link between poverty and environmental degradation (WCED, 1987; World Bank, 1992; Mink, 1993; Dasgupta and Mäler, 1994; Reardon and Vosti, 1995). Where credit and insurance markets are missing or imperfect, poverty restricts households' ability to make resource-enhancing or soil-conserving investments. In the case of extreme destitution, immediate survival needs and food security may be overriding objectives driving household behaviour thereby shortening the planning horizon of the poor. When immediate survival is threatened, households without sufficient assets to fall back on may lack the ability to forfeit current consumption to undertake resource-conserving or enhancing investments needed to meet future consumption. The positive correlation of high discount rates with poverty may therefore mitigate resource- improving or conservation investments with long gestation and payback periods (e.g. tree planting, installation of terraces for soil and water conservation, etc.) (Holden *et al.,* 1996; Pender, 1996). Thus, poverty may worsen environmental degradation. Peasant households in poverty-ridden and degrading areas of the Ethiopian highlands may thus be caught in a mutually reinforcing cycle of poverty and land degradation. The poverty-environment link may be conceptualised as in Figure 1.

The production, consumption, and investment strategies of peasant households determine the links between poverty and the environment. The livelihood strategies and decision behaviour of rural households are determined by the asset poverty of the household and other exogenous conditioning variables, like population pressure, technological options, rural infrastructure, the policy and institutional framework, and so forth, under which peasant households operate (Reardon and Vosti, 1995). The strength and direction of poverty-environment links in a given setting, therefore, depend on the depth, type, and spread of poverty, on the type of the environmental problem, and the influence of a multitude of exogenous variables (policies, markets, institutions, technologies, population pressure, etc.). When market imperfections limit the availability of rural credit or the fungibility of household assets required for consumption and investment needs, the level and type of household poverty determine the livelihood strategies pursued and the kind of activities and investments undertaken.[2] Household assets (land of varying quality, trees and livestock capital, financial capital, human capital, etc.), characteristics (discount rates, composition, dependency ratio, age, education, etc.), access to off-farm income, the technological setting, etc., affect the production, land use and investment decisions. Market imperfections may lead to interdependence between production, consumption and investment decisions of farm households, which may have strong implications for poverty-environment links. Factors exogenous to the household determine the market and technological options available to rural households and condition the type of land use and investment decisions undertaken. The resulting links between poverty and environment thus dictate the development pathways, the level of household poverty, and the sustainability of the production system.

2.2. Factors conditioning the poverty-environment link in Ethiopia

As depicted in Figure 1, the strength and direction of change in the causal links between poverty and environment in peasant agriculture are conditioned by factors exogenous to the household. Depending on the degree of influence and policy interventions, these exogenous variables may accentuate the problem and lead to worsening poverty and environmental degradation or help reverse the problem and lead to poverty reduction and sustainable land use. These variables include factors related to population pressure, technological stagnation, and pervasive market imperfections and policy failures, which may jointly be referred to as institutional failures.

2.2.1 Population pressure

Economic theory suggests two possible paths of agricultural change in response to increasing population pressure. The neo-Malthusian school following Malthus (1798) maintains that increasing subsistence demand and high population growth will impose an ultimate limit on food-production potential through deterioration of the resource base. An opposing theses by Boserup (1965) related to the theory of induced technical and institutional innovation in agriculture (Hayami and Ruttan, 1985), however, suggests that population growth and improved access to markets increase the scarcity of land and spur land-improving or land-saving technical change that raises production per unit area.[3] The role of population pressure and market access for intensification of agriculture is supported by empirical evidence (Pingali *et al.*, 1987) and is consistent with evolution of farming systems (Ruthenberg, 1980). However, sustainable land management and productivity growth do not always seem to follow rural population growth (Lele and Stone, 1989; Heath and Binswanger, 1996). Depending on the market and policy framework and the ecological setting, responses to population pressure may take one of the two development pathways: labour-led or policy (capital)-led intensification (Lele and Stone, 1989; Reardon and Vosti, 1995). Where conducive institutional and ecological conditions prevail, a capital-led intensification path in which land users augment their labour with capital investments that enhance or sustain the resource base would ensue. In the absence of such enabling conditions, sustainable intensification will fail to take place.

In the Ethiopian highlands, unfavourable policies towards peasant agriculture, technological stagnation, and political instability (wars) have worsened the combined effects of poverty, rapid population growth and environmental degradation (Heath and Binswanger, 1996). The result has been the lack of induced technical and institutional innovations (Boserup effects) that help offset the effects of poverty and increasing subsistence demand, resulting in scenarios that resemble a neo-Malthusian response (Grepperud, 1996; Shiferaw and Holden, 1996). Thus, in lack of opportunities to extensify, investment-poor households unable to follow the capital-led intensification path find themselves both accentuating the rate of degradation and becoming vulnerable to its adverse productivity effects. As noted earlier, human and livestock density is highest in the highlands and the per capita land availability is falling. Some studies indicate a 1.7% decline in land-man ratio per year (from 0.4 in 1984 to 0.32 in 1995) (Mamo, 1995). In addition to scarcity of land, population growth and degradation of land have also led to fragmentation of holdings.

2.2.2 Technological stagnation

In much of Ethiopia, rural infrastructure is poorly developed, agricultural research is rudimentary, and new technologies for production or conservation are largely unavailable. Recent data indicate that improved seeds, irrigation, and fertiliser are used only on 0.71%, 0.97%, and 25.4% of the cultivated fields (CSA, 1996). The average rate of fertiliser (nutrients) application per ha of cultivated land is 17.5 kg (CSA, 1996). This compares with 69 kg in South Asia, 100 kg in East Asia, and 142 kg in Europe in 1989/90 (World Bank, 1992). Some progress which has been made in the last three decades by the Institute of Agricultural Research (IAR) and university-colleges towards generation of new technologies has been frustrated by severe shortage of qualified senior researchers and inadequate incentives.[4] The few varieties of cereals developed to date are also not very well suited to the low-input peasant agriculture system. Diversity of the country's agro-ecological system dictates that extensive adaptive research will be needed before new technologies preferred by peasants are released. Thus, some of the available high-yielding varieties may indicate what is possible under high input agriculture rather than what is feasible under the peasants' farming conditions (FAO, 1993). Research should also address the needs of farmers and be geared more towards stress-tolerant technologies. In view of the recurring droughts threatening the survival of many vulnerable people, strategies that reduce dependence on rainfed farming and technologies that tolerate moisture stress will be vital if the country is to emerge from the disgraceful poverty and the continuing dependence on food handouts.

Information on soil erosion-productivity relations or control measures is also scanty and unavailable to farmers. In an attempt to fill this gap, the Soil Conservation Research Project (SCRP) was set up in 1981 to gather basic data on erosion processes and generate soil and water conservation technologies suited to different farming and agro-ecological systems in the country. The SCRP, initially organised as a small unit under the Agricultural Ministry, has since then opened some six research stations in watersheds lying in different agro-ecological zones.[5] Although the SCRP has generated extensive information on soil degradation processes and tested the effectiveness of some conservation techniques on experimental plots, failure to integrate socio-economic aspects, shortage of funds and qualified local manpower, and lack of a conducive organisational set up, have all hindered progress in soil and water conservation research. Hence, suitable conservation technologies that offer immediate benefits to land users are unavailable, and the majority of peasants only use age-old methods which have not been effective to counter the increasing soil degradation problem. Some soil and water conservation methods introduced in the last couple of decades are installed on less than 10% of the erodible lands.[6] As in the case of agricultural research undertaken by other institutions, the research carried out by the SCRP also suffers from weak extension liaison and integration with the activities of development agencies.

2.2.3 Institutional factors

Market and institutional developments in rural areas (Hoff *et al.*, 1993; North, 1990), behavioural and material determinants of production relations in agriculture (Binswanger and Rosenzweig, 1986), technological innovation (de Janvry *et al.*, 1989), and government policies and incentives can encourage or discourage emergence of sustainable pathways of development. Of particular importance are the functioning of labour, land, capital (credit), insurance, and input/output markets; the security of land tenure; and policy incentives and/or distortions. Peasants' responses to conserve or degrade resources, therefore, depend on the institutional framework (nature of rural markets, prices, polices, etc.). Some of the major factors related to institutional failure in the Ethiopian context are discussed below.

(a) Incomplete property rights: Insecurity of land rights is generally regarded as one important deterrent to conservation investment (e.g. see Southgate, 1988; Scherr and Yadav, 1996) and this has been confirmed through empirical adoption studies (Norris and Batie, 1987; Nowak, 1987). When a system of property rights fails to provide sufficient security to private agents to reap future benefits from their investments, they may fail to undertake otherwise profitable and environmentally benign investments. Social efficiency requires that resource rights be exclusive, transferable, enforceable, and universal (i.e., account for all costs and benefits of use, including external costs and benefits). Rights in land, however, vary in terms of the above attributes from open access (*res nullius*) on one extreme, to private property on the other. The continuum between the extremes includes communal (*res communis*) and state property. Private rights may also be incomplete due to lack of universality, temporal attenuation (e.g. short-term leasehold), spatial attenuation (e.g. use rights that restrict the type of land use), high insecurity and lack of transferability (e.g. usufruct rights), or a combination of all these. Resources under communal ownership may be used efficiently, but suffer over use when customary rules of regulating access are undermined. Open access does not prescribe rules of regulating use; everyone is a stakeholder in the resource. Lack of excludability is a disincentive to private investments.

In Ethiopia, land was nationalised after the 1975 land reform policy and still remains under state ownership while peasants only possess insecure use rights that can be revoked without compensation. The reform policy abolished all kinds of tenancy and labour hiring by private land users. Private land markets are still outlawed and land does not have a legal asset value to the user. Since the reform, Peasant Associations have frequently redistributed land up to 1991 to new landless claimants. When abandoned land (due to death or emigration) was in scarce supply, land was usurped from other users without compensation and allocated to new claimants. During the era of collectivisation, primacy in allocation of land and other resources was granted to producers' co-operatives, thus private users had to forfeit their use rights, including any investments made on the land, in case a parcel was needed by the co-operative. In the post-1991 transitional period, all land distribution was banned until the land issue is resolved by a referendum. The issue was, however, addressed in the new constitution, which retained state ownership of land but granted peasants rights to obtain land without payments and protection against eviction from their possession. A new land redistribution policy was, however, implemented in early 1997 in the Amhara Kilil (Regional State). Unlike the pre-1991 land redistribution which often considered family size and land quality, the new redistribution in the Amhara Kilil has reportedly categorised peasants into different arbitrary classes and allotted less than 1 ha of land, irrespective of family size and land quality, to households who served in the youth, women or peasant associations or in the army during the previous regime or those considered to be remnants of the feudal class (EHRCO, 1997). Peasants' capital investments made on such expropriated lands were also taken without compensation. Such policies that deny peasants their vital means of livelihood are likely to further diminish their confidence to undertake land-improving and conservation investments and worsen rural poverty, inequality and food insecurity. Although little research has been done on land tenure issues, Ethiopian researchers seem to concur about the disincentive effect of state ownership of land on resource-improving or conservation investments (Abegaz, 1994; Rahmato, 1994; Aredo and Regassa, 1995).[7]

(b) Imperfect capital and insurance markets: Rural capital markets in developing countries are often dominated by informal sources characterised by segmentation, rationing, and high rates of interest on small sums offered for short duration. Problems of moral hazard and adverse selection emanating from informational asymmetries often cause imperfections in capital and insurance markets (Stiglitz and Weiss, 1981; Hoff and Stiglitz, 1993). As imperfect as they are, existing credit services provide short-term lending for productive activities and consumption smoothing, while there exists a serious credit market failure for long-term investments like land improvement and soil conservation. These investments do not offer attractive rates of return in the short-term. Moreover, coupled with the high opportunity cost of capital, consumption smoothing problems and cash and liquidity constraints may be associated with high subjective rates of time preference[8] among the rural poor (Pender and Walker, 1990; Holden *et al.,* 1996; Pender, 1996). In an ideal perfect capital market case, all farmers would operate with the same discount rate, which would equal the market rate of interest. However, where capital is scarce and rates of interest are high, the need for short-term consumption smoothing may drive personal rates of discount above the social rate of discount. In general, individual users would fail to undertake investments with rates of returns lower than their subjective rate of discount. To the extent that private rates are higher than the social rate, the set of projects with high up front costs and long payback periods (typical of land conservation and productivity-improving investments), undertaken by private agents would be socially sub-optimal, or might not be undertaken at all. Such differences in the rates of discount may lead farmers to ignore or insufficiently internalise on-site user costs of soil erosion (even with complete information and property rights) and impose an intergenerational externality. Moreover, when future returns tend to be more uncertain (e.g. due to fear of expropriation), risk-averse decision makers will favour projects with short payback periods, and will be less motivated to invest in projects with long-term benefits.

In Ethiopia, limited formal credit is available only for short-term loans for fertiliser. Formal credit for consumption smoothing or long to medium-term loans for investment in land, livestock or other resources is lacking. Informal credit in rural areas is characterised by fragmentation, rationing, and high interest rates available as short-term loans mainly for consumption smoothing. The average estimated real rate (discrete time) of discount in a relatively high potential area with good market access was 54% (Holden *et al.*, 1996). The rate of discount was also inversely correlated with ownership of productive capital (oxen). Moreover, due to high transaction costs, and adverse selection and moral hazard problems, crop or livestock insurance is unavailable.

(c) Imperfect information: Soil erosion is a gradual process which may take several years, especially on deeper productive soils, before the effect of nutrient depletion is reflected in declining yields. Technological change, productivity growth, and adoption of offsetting inputs may further mask the effect of soil loss on yields (like fertilisers that supplant lost nutrients). There is also a severe shortage of empirical information on the effect of soil erosion on land productivity (on-site effects). When farmers are unaware of the potential on-site user costs of soil erosion, they may impose an important externality on the society and future generations. Likewise, uncertainty also compounds the potential future uses in which a piece of land could be put and the resulting future profitability. The quasi-option value of the land may also be high when land uses are irreversible. Past soil conservation research in Ethiopia, like in many developing countries, also focused on developing or testing erosion control techniques (often mechanical) designed to keep the soil in place with little emphasis on their adaptability and economic efficiency. This implies that productivity enhancing conservation technologies suitable to farmers conditions are often unavailable. Apart from lack of suitable technologies, the diffusion of any available information to peasants is highly constrained by shortage of extension staff. On average, one development agent serves 2520 peasant households (FAO, 1993). The situation is even worse in inaccessible areas and low potential zones. Since scientific and technological progress offers external benefits and use may not be excludable, public investment in research and extension is essential for generating (or adapting) and disseminating the required information.

(d) Transaction costs: In the absence of (prohibitive) transaction costs, the allocation of resources is symmetric to the assignment of property rights (i.e., despite the widely varying distributional impacts, an efficient outcome results irrespective of the assignment of rights) (Coase, 1960). However, when transaction costs are prohibitive or when the affected parties are large, profitable trade and production decisions may not be undertaken even when rights are properly defined. High transaction costs and free rider problems are likely to be important in community level resource management where broader participation is necessary, as in soil conservation or tree planting on communal land. Due to high transaction costs, markets for natural resource inputs and less erosive crops may also be very thin or entirely missing. When the endogenous price of a good, which equates supply and demand, lies within the price band, farm households prefer self-sufficiency rather than participating in markets. The rugged topography of the highlands, coupled with poor rural infrastructure and dispersed settlement patterns, limit accessibility of rural areas. The communications network is one of the least developed in Africa; road density is only 1.2 km/100 km^2. An estimated 75% of highland farmers live more than a half-day walking distance from the nearest road (FAO, 1986). Lack of market outlets also leads to considerable seasonal variation of farm-gate prices. In view of underdevelopment of rural roads, most households use animals for transport (donkeys, horses, mules and camels).

(e) Policy failures: Governments often unwisely intervene into otherwise well-functioning markets and distort existing incentives or create adverse externalities in their unsuccessful attempt to internalise market failures. Such misguided interventions impede the market mechanism from allocating resources more efficiently and exacerbate existing market failures. Market failures are thus partly policy failures emanating from government failure to establish enabling conditions for markets to function efficiently or failures to internalise externalities. Policy-induced distortions that create perverse incentives and encourage depletion and environmental degradation include underpricing of exhaustible resources (e.g. irrigation water, fuelwood, land, etc.), subsidising extractive use of resources (e.g. forest logging, mining), land grabbing incited by rights based on forest clearing, overvalued exchange rates, and subsidies for inputs with significant external effects (e.g. pesticides). Therefore, policy reform and intervention to mitigate market failures should first aim at removal of policy-induced distortions that perpetuate perverse incentives. As Panayotou (1993) argues, reforming policies that carry a double-edged sword (i.e., detrimental to both the economy and the environment) would represent a win-win approach. Distributional implications could also be positive as increased efficiency and faster economic growth may offer some trickle-down effects for poverty alleviation.

In Ethiopia, consistent with the general neglect of the sector in development theory, prior to 1974, policy support to agriculture was very limited. Some of the reforms that followed the 1974 revolution, like "land to the tiller", were later liquidated by misguided policies and ardent socialist orientation. Until the late 1980s, agricultural input and output marketing remained under state monopoly while pan-territorial grain marketing prices were fixed below the free market level. Policy support for credit, input distribution, output marketing, and extension was mainly targeted towards co-operatives and state farms that jointly accounted for only 10% of the agricultural produce. Thus, excessive surplus extraction and discriminatory policies discouraged private peasant production. Coupled with insecure rights, the fall in the relative profitability of private land use is likely to have discouraged investments in land. Although the 1975 land reform policy enabled many landless farmers to gain access to land, the reform failed to stimulate agricultural development and sustainable land use due to insecurity of use rights and other misguided policies that followed the reform.

3. A Summary of the Research Findings

3.1.Theoretical findings

A dynamic farm-level soil conservation model was developed to explore the underlying factors that may lead to the prevalence of a Pareto-relevant land degradation externality. A soil fertility index was used as a state variable. A soil-degrading but productive input, and a soil-conserving input (that may increase or decrease yields) were used as choice variables. Farm-level investment response to changes in economic incentives, soil quality, and user cost of soil erosion were investigated. Moreover, the potentials and limitations of price-based instruments (input taxes/subsidies or taxes on soil loss) suggested by the comparative statistic results were further examined. The results show that:

(1) When input/output markets are perfect and where external costs of soil erosion are absent, the level of abatement achieved by private land users will closely mimic the socially optimal path of soil use. Under the circumstances of peasant agriculture, none of these conditions are likely to hold. Thus, the private user cost of soil erosion and hence the smallholders' intertemporal plan of soil use, can differ from that which maximises social welfare even when external (off-site) costs of soil erosion are absent. When factor market are imperfect, intertemporal markets are missing, and tenure is insecure, the interlinked effects of poverty, environment and population growth can lead to deviation between private and social user costs and the respective optimal paths of soil use.

(2) Short run investment responses in land quality depend on the productivity effect of conservation. (a) When the conservation input adds to the productivity of the soil, the effect of changes in output price, the level of soil fertility, and the user cost of soil erosion will depend on the gain in productivity and the effect on soil degradation. When the effect on production dominates the effect on soil degradation, the use of both inputs increases with a rise in output price and soil fertility. When the effect on soil degradation is more significant than the effect on production, an increase in the user cost of soil will favour the use of the soil-conserving input, but discourage the use of the soil-degrading input. A rise in the cost of an input will, however, unambiguously discourage the use of that input regardless of the effect of conservation on production. (b) When the conservation input has either a neutral or negative impact on the productivity of soil and the yield increasing input, a rise in the price of output, an increase in soil quality, and a rise in the cost of the soil-conserving input, would encourage more intensive use of the productive but soil-degrading input over that of the soil- conserving input. A rise in the user cost of soil and an increase in the cost of the productive input, however, tend to induce improved land management.

(3) In the long run, in farming systems that are based on highly erodible soils with low returns to the use of inputs, an increase in output price, a rise in the cost of conservation, an increase in the discount rate or a subsidy on the use of the soil-degrading productive input, tend to lower the steady state productive capacity of the soil. Hence, under plausible assumptions, a per unit subsidy on the use of the soil-conserving input or a tax on the use of the soil-

degrading input or any policy which tends to lower the real discount rate will have an unambiguous effect of increasing the long-term soil quality.

(4) Taxes on predicted levels of soil loss or input taxes/subsidies could be used for regulation of the soil erosion externality. However, mandatory soil conservation policies in the context of peasant farming are likely to have limited potential due to imperfect information, and high enforcement and transaction costs. The peasant household subject to a regulatory policy may also face a difficult trade-off between the demand for conservation and the need to meet livelihood requirements especially when conservation does not confer immediate economic benefits to the poor. Therefore, in the near-term, the potential for soil conservation in resource poor environments depends on provision of subsidies for conservation effort or availability of multipurpose technologies that also enhance productivity of the poor's assets. In the long-term, a poverty alleviation strategy which would lower the subjective rate of discount and encourage investments with long-term benefits is highly imperative.

3.2 Determinants of conservation investments

Econometric analysis was done on data collected from 452 plots in an area where soil conservation structures were introduced in the past through coercion and food-for-work incentives. Peasants' voluntary decisions to keep or remove these conservation practices without program benefits or coercion were modelled as a two-stage decision process: perception of the erosion problem, and the decision to adopt conservation technologies. The results indicate that:

(1) Soil erosion perceptions are determined by factors related to erosion potential, access to information, perceptions of technology attributes, and the intensity and type of land use. (a) Physical erosion potential of the plot (slope) is the most important determinant of the perception of soil erosion. The higher the slope category of the plot, the higher the probability that recognition of soil erosion will be above any fixed level. (b) Access to information through extension and other channels were found to be positively associated with recognition of the soil erosion problem. (c) Cultivated land per capita and livestock wealth were negatively correlated with soil erosion perceptions. (d) Peasants' perceptions of technology-specific traits also seem to be highly associated with recognition of soil erosion as a problem. Those who perceive the traditional technique as highly ineffective for retaining soil seem to have higher recognition of the threat of soil erosion. (e) Land users are also more likely to recognise the erosion problem on intensively cropped lands and on prime agricultural land than on less intensively used land.

(2) The decision to dismantle or retain conservation structures depends on a multitude of factors. (a) Land users who perceive a severe threat of erosion are less likely to remove structures. (b) Peasants are also less likely to remove conservation structures on larger plots than on smaller plots, and on steeper slopes than on shallower slopes. (c) Peasants who anticipate higher returns under the new conservation technologies, or had a positive attitude towards new technologies, or those who are more informed about new erosion control practices, are less likely to remove conservation structures. (d) However, the older the head of the household, the larger the family size, and if a parcel is located in the major cropping zone, the higher the likelihood that structures will be removed. (e) Land-scarce farmers with low land-man ratios were also found to have a high propensity to remove conservation structures. This indicates the limitations of autonomous intensification to stimulate land-improving or conservation investments. It also lends evidence to the argument that autonomous intensification triggered by population pressure alone is unlikely to encourage sustainable land use unless supported by appropriate policies that enhance investment in land quality. In the presence of conducive policies, profitable technologies, and in areas with good market access and agro-climatic conditions, population pressure can, however, lead to sustainable land management (e.g. Tiffen *et al.* 1994).

(3) Peasants are unlikely to adopt erosion control practices unless they anticipate that the shift to a conserving practice will improve their immediate well-being. Thus, multipurpose technologies that enhance productivity of land and help counter soil erosion are urgently needed to promote sustainable land use in degrading areas. Specific policies addressing the constraints and limitations faced by peasants are needed to make conservation in the best interest of the land users. Such policies for sustainable land use in poor degrading areas may include technical change, institutional support, market access through investment in rural infrastructure, and provision of targeted incentives. These are likely to be crucial challenges for soil conservation policy in Ethiopia and other similar developing countries in the future.

3.3 Analysis of farm households' land use and conservation decisions

A farm household is a composite of the consumer's, the worker's and producer's households. Peasant smallholders in Ethiopia are thus farm households, which may respond to changes that affect their attributes both as producers and workers/consumers. In making their land use and conservation decisions, smallholders often face many constraints due to market imperfections, tenure and liquidity problems and the need to meet subsistence requirements from home production. When some markets fail, production and consumption decisions are interdependent and linked through endogenous prices. The farm household perspective (Singh *et al.*, 1986) that integrates the dualistic production and consumption decisions provides a suitable framework for the study of peasants' resource use behaviour.

The results from the study that develops a nonseparable farm household model indicate that:
(1) The productivity effect of conservation and the level of internalised user costs of soil erosion influence farm households' resource use and land use decisions. (a) When the peasant is not internalising the user costs of current production activities, no land conservation is likely to occur unless the conservation technology is enhancing productivity. (b) When conservation is not anticipated to enhance short-term productivity, lower yields and high costs of installation prohibit adoption of conservation practices even when the user costs are internalised at the average estimated real rates of discount (54%). (c) When conservation is yield depressing, only if discount rates are as low as 5% would some conservation become part of the optimal plan. This may explain the general lack of conservation in the study area. This provides additional evidence to the earlier result that policies to enhance soil conservation should look for new techniques that improve the welfare of the poor while also conserving the resource base. Where this is lacking, society may have to look for other incentives to persuade peasants to install conservation practices.

(2) Under plausible assumptions, even in the long run, conservation will not be part of the peasants' optimal production plan when it reduces the productivity of the land. Only when the user costs are internalised at low rates of discount (less than 10%) would conservation enter the optimal plan. When anticipated returns with conservation are no different from without conservation, zero conservation is also likely to be optimal unless user costs are sufficiently internalised. Although widespread conservation adoption appears to take place in the long run when user costs are accounted at the estimated rate of discount (54%), this may not be achievable unless some incentives are used in the short run to induce the land user to embark on conservation. Apart from secured rights to land, extensive educational and outreach programs may be needed to increase awareness to user costs and encourage individual users and the community to counter the soil erosion problem. When conservation adds to current yields, all

erodible lands are likely to be treated with conservation structures whether or not land users care for future productivity impacts of current soil erosion.

(3) The effect of credit/cash constraints for fertiliser on production and conservation decisions depends on the productivity of conservation practices. (a) When conservation is either yield-depressing or neutral, relaxation of the cash/credit constraint for the fertiliser input seems to discourage conservation. This indicates the need for innovative cross-compliance type policies that link input and credit subsidies with the requirement to install conservation. (b) A rise in fertiliser prices in the face of a credit constraint discourages conservation when conservation is not yield-enhancing. A rise in fertiliser prices, under a credit constraint, crowds out conservation as households divert labour to meet subsistence needs. (c) With productive conservation, a rise in fertiliser prices encourages conservation initially, but only until the input prices increase beyond some threshold level. This implies that an increase in fertiliser prices without provision of rural credit facilities is likely to discourage conservation effort.

(4) Peasants' production and land conservation decisions are, therefore, influenced by factors related to their dual nature as units of consumption and production. Soil erosion reduces the future productivity of land and conservation helps to mitigate this future loss in productivity. Thus, individual land users will not find conservation to be in their best interest if they do not consider the on-site costs of production activities in their current decision making. High discount rates and short planning horizons contribute to this effect. Subsistence pressure and need for consumption smoothing (food insecurity) may lead to high rates of time preference while insecurity of land tenure may lower expected returns to conservation. Even if peasants are aware of user costs and are willing to internalise them, the productivity of conservation and its effect on their short-term welfare influence the level of conservation achieved.

3.4 Analysis of incentives for soil conservation

The problem of land degradation in areas with fast growing populations affected by poverty and malnutrition is increasingly necessitating government intervention. From the viewpoint of economic efficiency alone, the mere existence of land degradation does not, however, make public intervention Pareto-improving or socially optimal. Public intervention for soil conservation requires that the existence of a Pareto relevant land degradation externality is verified, and that intervention should improve social efficiency. The study undertaken to analyse the efficiency of some incentives for soil conservation shows that:

(1) Where rural poverty is widespread, interlinkage of markets through cross-compliance (eligibility for production incentives is conditioned by the need to install conservation practices on erodible lands) can be an innovative approach for countering soil erosion without adverse impacts on the welfare of the poor and the marketed surplus of food. Such policies may thus represent improvements in efficiency, equity, and environmental quality (win-win-win policies). The efficiency of the incentives, however, depends on the productivity effect of conservation technologies and the discount rate. (a) When conservation technologies are counterproductive and reduce immediate household incomes, fertiliser subsidies linked to conservation do not improve social efficiency unless the rate of discount is very low (close to 5%). (b) Seed subsidies and a mix of seed and fertiliser subsidies linked to conservation are, however, more efficient since they enabled large reductions in erosion damage at low cost. But, such incentives are also socially inefficient when the rate of discount is as high as 20%. (c) When structures are yield-neutral in the short run, the cross-compliance policies for fertiliser, and a mix of seed and fertiliser inputs are able to reduce erosion-induced productivity loss efficiently. But, the efficiency of these incentives also drastically falls as the social rate of discount rises above 10%, and it becomes inefficient at the 20% rate.

(2) The interlinking of markets (cross-compliance) was also found to reduce the soil erosion externality more than input subsidies unlinked to conservation. Production subsidies unlinked to conservation artificially boost the short-term profitability of farming and lessen the need to invest in conserving the soil stock, and thus conservation investments gradually vanish as the level of the subsidy increases.

(3) At low rates of discount, the cost-sharing policy (incentive payments for conservation labour) is not efficient when conservation is yield-depressing. It, however, enables complete conservation on erodible uplands efficiently when conservation is yield-neutral in the short run. When peasants have sufficient incentives to maintain structures after installation, utilising their own labour for conservation during periods of low farm activity through incentives like cash or food-for-work programs that also provide employment opportunities for the poor may, therefore, be a good approach for soil conservation. If such incentives can be made available through external assistance, land productivity decline and loss of biodiversity from expanding agricultural frontiers can be mitigated without imposing a heavy strain on the economy of poor countries.

(4) The efficiency of the incentives was also found to depend on the user cost of soil erosion, the social rate of discount, and the life time and productivity effects of conservation structures. An

increase in the user cost, a decrease in the rate of discount, and an increase in the life of bunds improve the efficiency of the incentives. The user costs depend on the productivity impact of soil erosion, output prices, and the social rate of discount. A decrease in soil depth and technical change are most likely to raise the productivity impact of soil erosion. Increase in output prices and a decrease in the discount rates also raise the user costs. Moreover, taxing the most erosive crop (teff) is found to be more effective in abating soil erosion than supporting the prices of less erosive crops (pulses). The pulse price support policy did not change behaviour due to low prices and productivity of these crops.[9] General equilibrium effects of price policies were, however, not captured and price effects may need to be interpreted cautiously until such effects are investigated in future work.

4. Implications for Food Security

Food security refers to sufficient food availability and access by all people at all times to meet the dietary needs for a productive and healthy life (von Braun *et al.*, 1992). Thus, the key elements that determine food security at any point in time are *availability, accessibility*, and *utilisation*. Availability is the supply-side indicator of food security achieved when sufficient supplies of food of appropriate quality are consistently available to all individuals. Food availability at the national level is a function of domestic production, carryover stocks, and imports (both commercial and food aid). Accessibility refers to access by all households and all their individual members to obtain adequate food that meets dietary needs for a productive and healthy life. Accessibility failure relates to Sen's concept of entitlement failure (Sen, 1981). National food availability is thus not a sufficient condition to household food security. The household's capability to command sufficient food depends on its control over resources as conditioned by own income and exogenous transfers. Peasant households may fail to command access to sufficient food due to several factors: bad weather, pests, land degradation, poverty, adverse policies, social unrest, lack of access to off-farm income, lack of food insurance, and so forth. Utilisation refers to the ability of individuals to make proper biological use of the food consumed. Thus, in the broadest sense, food security is not ensured even when individuals have access to sufficient food since the nutrients gained can be lost through poor health (e.g. parasitic infection).

The joint effect of widespread poverty, land degradation, population pressure, institutional failures, political turmoil, and so forth in Ethiopia has in recent times begun to manifest itself in deteriorating food security even in years of good weather for agriculture. Some studies indicate that areas that suffer frequent famines are also those exhibiting highest annual rates of soil erosion (Hurni, 1988). Soil degradation and loss of vegetative cover are believed to have increased the susceptibility of the rainfed peasant production system to environmental stress (FAO, 1986; Dejene, 1990). Coupled with this is lack of technological change in peasant agriculture and its dependence on nature. Although the country is well endowed with streams, rivers, lakes and ground water to irrigate some 3.7 million ha, only 2% (90, 000 ha) of the potential has as yet been developed. The irrigated area is mainly used for large-scale commercial farming. This is despite the fact that some 60 to 65% of the area of the country lies in drought-prone and regularly food deficit areas (FAO, 1993). The degradation of the resource base and excessive reliance on unpredictable rains accentuate the effect of poverty. Zegeye and Habtewold (1995) estimate that some 27 million people (60% of the population in 1992) are food insecure and live below the poverty line. Food insecurity is highest among poor farmers, farmers in marginal areas, pastoralists inhabiting areas with precarious rainfall, and the urban poor. Vulnerability to famine, however, tends to be worse in rural areas. About 26% of the rural population (13 million people) and 50% of the urban population (4 million people) are chronically food insecure. About 1 million people are affected by drought every year (ibid.).

All the available indicators show that Ethiopia is one of the most food insecure countries in sub-Saharan Africa. As a reflection of the rainfed nature of agriculture, total domestic food crop supply shows extreme annual variations (see Figure 2). For a period of three decades (1964/65-93/94), the coefficient of variation of food crop production was 16.5%. During this period, the average annual rate of population growth was about 3.15%, but food crop production grew only by 0.44%. Domestic supply suffers substantially during years of drought as in 1973-78 and 1984/85. The effect of this has been an average per capita domestic food availability decline of 2.7% per year (see Figure 3). Since the early 1970s, domestic food grain production has rarely been above 150 kg/person. In 1993/94, per capita food availability was about half of that in 1964/65. Shortfalls in domestic food production have been partly compensated by growing imports of food mainly through aid (see Table 1).[10] While food aid was regularly needed even in years of amiable weather conditions, years of drought and unsuitable growing conditions threaten famine with increasing severity and extent. During years of drought, dependence on food aid reaches up to 15%, while total imports may reach up to 17% of the total annual availability. Even with increasing food imports (aid and commercial), the total availability has barely satisfied daily dietary requirements even at 1700 calories/person. The deficiency would be much larger if recommended dietary requirements of 2100 calories/day were considered.

Although self-sufficiency has remained the expressed goal of the two governments following the imperial regime, even at bare minimum dietary levels the country is rarely able to meet more than 75% of its food requirements from domestic production. Years of drought lower the self-sufficiency ratio close to 60%. This is a reflection of the severe structural bottlenecks coupled with poverty and population growth (discussed above) that continue to hinder transformation of peasant agriculture and promotion of sustainable land use in the country. There is an urgent need for setting up policies that foster agricultural development and remove all hindrances that deter voluntary participation of the peasantry in the process of development and resource conservation. Although enormous untapped potential for revitalising agriculture and facilitating economic development exists, the country's current and future ability to harness this potential will also very much depend on prevalence of sustainable peace and institution of a system of popular governance.

End Notes

[1] Land degradation refers to a temporary or permanent decline in the productive capacity of the land or its potential for environmental management. Land in this definition includes not only the soil resources, but also the water, vegetation, landscape and microclimatic components of the ecosystem. Productive capacity is attainable annual output (of product yield, of natural vegetation, water flow, and so forth) at a fixed level of non-land inputs. Productivity decline may be directly due to deterioration of soil quality or indirectly through infestation of degraded soils by persistent weeds that reduce yields. Soil quality may be degraded through three processes: physical degradation such as wind and water erosion and compaction; chemical degradation such as salinization, acidification, nutrient depletion, and chemical or heavy metal contamination; and biological degradation which includes loss of soil organic matter and the amount of carbon from biomass and reduced microbial activity. Environmental management includes recycling of nutrients, amelioration and filtering of pollutants, transmission and purification of water, and encouraging vegetative growth to act as sinks for greenhouse gases (NRC, 1993; Scherr and Yadav, 1996). Diminution of soil quality in peasant agriculture in the Ethiopian highlands is mainly related to physical and biological degradation of soil.

[2] In their analysis of the poverty-environment links, Reardon and Vosti (1995) distinguish between 'welfare poverty' and 'investment poverty'. Since a poverty indicator based on a welfare criterion may exclude households that are still poor in key assets to be able to afford critical resource-enhancing investments, they suggest the use of 'investment poverty' for analysis of poverty-environment links. The ability to invest in resource improvement requires that households be above the 'investment poverty' threshold, which depends on the costs and types of investments needed and the household's asset composition.

[3] Boserup (1965) suggested eight principal effects of population growth: reduced fallow period, increased investment in land, shift to machines and animal traction, increased soil fertility maintenance, reduced average cost of infrastructure, increased specialisation in production, shift to secure land rights, and fall in communal land-man ratio. The theory of induced technological innovation that explains the rate and bias of technological change as an economic response to market forces and factor scarcity was later formalised by Hayami and Ruttan (1985).

[4] Although rises in salaries have been introduced recently, the devolution of part of the national research system into the ethnic regional states and weak linkages between local research institutes and IAR is hindering effective utilisation of the scarce scientific personnel. The shortage of senior researchers is a result of the exodus of scientists mainly after the political problems since the 1970s.

[5] The SCRP research stations comprise Maybar (since 1981, Wello), Andit Tid (1982, North Shewa), Anjeni (1984, Gojjam), Gununo (1982, Sidamo), Hunde Lafto (1982, Hararghe), and Dizi (1988, Illubabor). There has also been one station in Eritrea (Afdeyu).

[6] Efforts to install conservation measures were initiated after the 1975 land reform and establishment of the Peasant Associations (PAs), which were instrumental for mobilising labour and enforcement of coercive approaches. This was further expanded with the involvement of mainly the World Food Program since the early 1980s which provided food-for-work (FFW) incentives for conservation activities. Structural measures, mainly earth and stone bunds, were built uniformly across regions with FFW incentives in food deficit areas of the highlands. Activities were mainly undertaken on an ad hoc basis often without the involvement of the

land user and, as noted elsewhere, their sustained adoption is becoming a problem. Approaches that improve the effectiveness of traditional methods may also be more successful than exotic methods.

[7] The effect of land insecurity on land-improving and conservation investments is likely to vary from place to place depending on past and current experiences of land users in maintaining use rights to land and their expectations about the future. Where peasants had limited interference, land security is likely to be mainly important for investments with long gestation periods such as tree planting and making terraces than other investments with relatively shorter payback periods.

[8] The rate of time preference is a measure of the consumer's subjective rate of discount, the increase in future consumption that would compensate for a loss of a unit of present consumption. This intertemporal rate of substitution is influenced both by diminishing marginal utility of consumption and the pure rate of time preference (preference for present consumption when consumption in the two periods is the same).

[9] Perennial crops (like coffee, chat, enset, etc.) were not, however, part of the farming system studied.

[10] In realisation of the country's inability to produce enough food for its growing population, the Relief and Rehabilitation Commission (RRC) was institutionalised in 1974 with a mandate of assessing national food aid requirements and providing early warning services to avert famines. (Lately, RRC has evolved to Disaster Prevention and Preparedness Commission.) Efforts to prevent future famines in Ethiopia should be aimed at establishing a political and institutional environment that can foster a national food security strategy based on enhancing productivity of peasant agriculture rather than sustaining charity from the donor community.

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Table1. Food production and deficits in Ethiopia ('000 tons of cereal equivalents), 1983/84-1993/94.

	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94
Total domestic supply[1]	6811	4982	5508.1	6337.4	6799.3	6910.7	7098.8	7625.1	6550.7	7895	7532
Food aid	208	869	799.2	570.3	823.8	572.8	537.5	894	1001	519.3	918.0
Net imports[2]	290	128.9	322.9	136	187.7	243.5	88.6	75.7	90.1	87	23
Total availability	7309	5980	6630	7044	7811	7727	7725	8595	7642	8501	8473
Per capita availability (kg/person)	178.2	139.6	149.9	154.0	165.5	159.0	153.9	166.2	143.1	154.3	150.0
Per capita availability (1983/84 =1)	1.0	0.78	0.84	0.86	0.93	0.89	0.86	0.93	0.80	0.87	0.84
Aid dependency ratio	2.8	14.5	12.1	8.1	10.5	7.4	6.9	10.4	13.1	6.1	10.8
Import dependency ratio	4.0	2.2	4.9	1.9	2.4	3.2	1.1	0.9	1.2	1.0	0.3
Total dependency ratio	6.8	16.7	16.9	10.0	13.0	10.6	8.0	11.3	14.3	7.1	11.1
Food deficits (182 kg/person or 1700 calories/head/day)	-155.1	-1815.0	-1418.9	-1280.5	-777.6	-1118.2	-1411.4	-814.6	-2077	-1526.9	-1810
Self-sufficiency Ratio (182 kg/head)	91.3	64.0	68.3	76.2	79.1	78.1	77.7	81.0	67.4	78.7	73.2

[1] Sum of total grain production adjusted for seed requirements and post harvest loss by 15%, *enset* and root crops, milk and meat.

[2] Total commercial imports less food exports.

Source: Zegeye and Habtewold (1995) and FAO (1993).

Figure 1. Poverty-environment links in peasant agriculture.

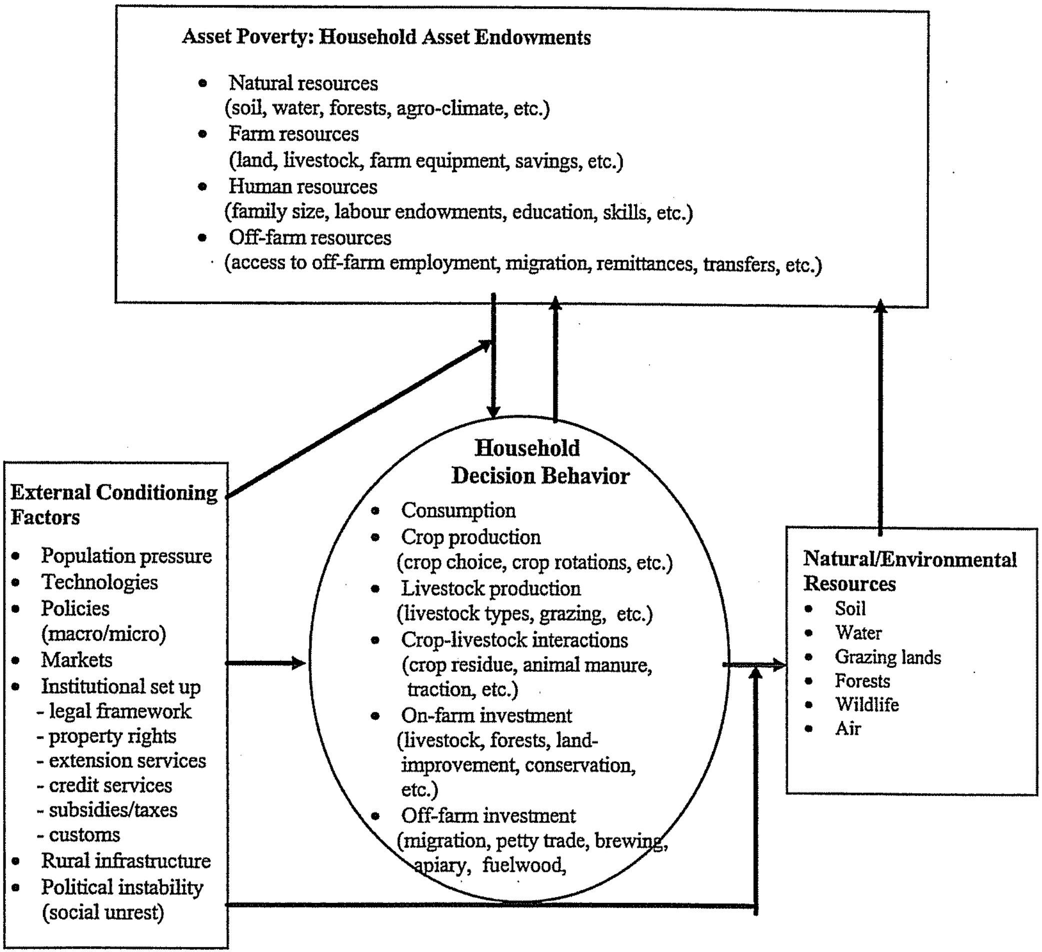


Figure 2. Trends in food crop production and population growth in Ethiopia (1964/65-1993/94)

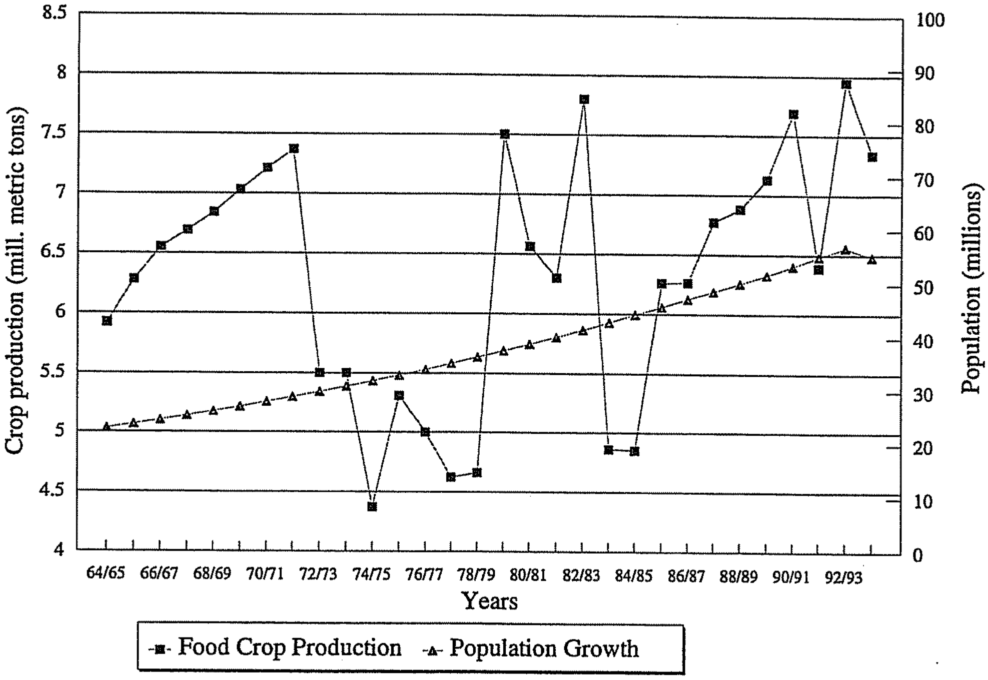
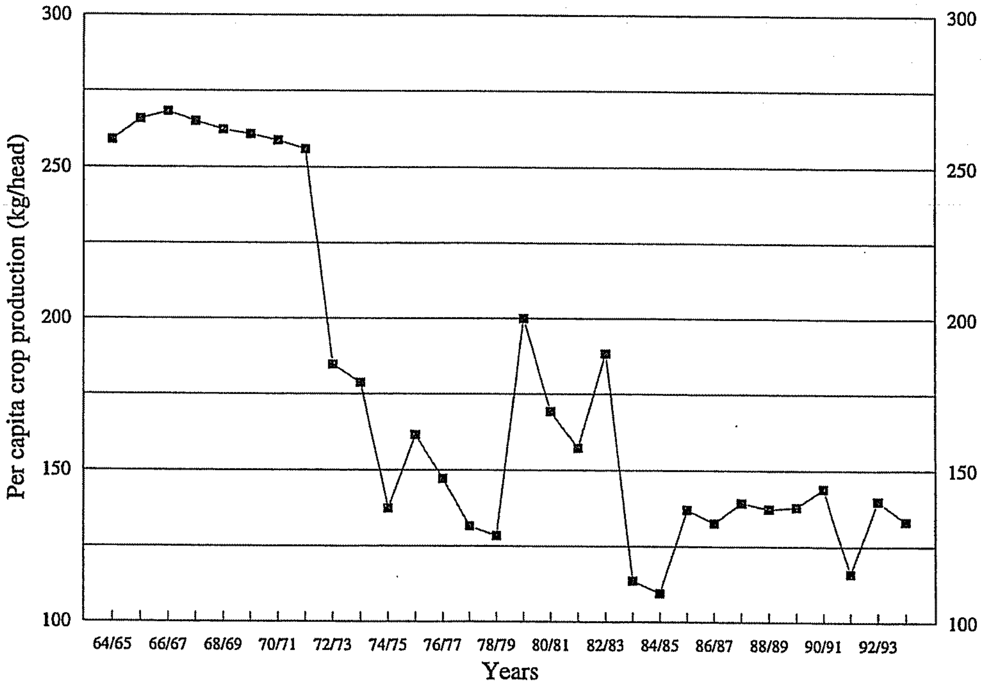


Figure 3. Per capita food crop production in Ethiopia (1964/65-1993/94)



Economic Analysis of Land Degradation and Incentives for Soil Conservation in Smallholder Farming: A Theoretical Development

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Abstract

The problem of land degradation is perhaps the most important environmental problem facing poor agriculture-based economies of the developing world. This paper attempts to develop a suitable theoretical framework for economic and institutional analysis of this problem in the context of smallholder farming. It presents the conditions that lead to deviations between privately and socially optimal levels of soil conservation and factors that lead to the divergence between private and social user costs of soil use. A dynamic farm-level soil conservation model is developed and used for a comparative static analysis of the smallholders' soil use problem and to examine the economic stimulus in terms of choice and level of use of conservation and productive inputs and the impacts on the short and long-term productive capacity of the land. The effect of using price based policy instruments as suggested by the comparative static results for endogenizing or mitigating the soil erosion externality is further examined and elaborated using a separate static model.

1. Introduction

In recent years, land degradation[1] and particularly that caused by soil erosion on sloping lands, is perceived as one of the most serious environmental problems affecting poor developing countries that heavily rely on agriculture and extraction of primary resources (Southgate *et al.*, 1984; WCED, 1987; Southgate *et al.*, 1990). To the extent the estimated economic costs of land degradation are reliable, the annual costs to various developing nations could be as high as 17% of the gross national product (Pearce and Warford, 1993). This indicates a significant environmental problem which could severely diminish the rate of economic recovery and the ability to produce sufficient food for the growing populations of the poorest segments of the world. For example, in Ethiopia, some estimates indicate that soil erosion causes a 4 mm annual net reduction in soil depth and a yield loss of 1-2% (Hurni, 1993), while FAO (1986) estimates an average annual yield loss of 2.2%. In Mali, soil erosion is estimated to cause an average annual yield penalty of 2-10% in terms of net farm income forgone (Bishop and Allen, 1989).

The problem of land degradation is more severe in smallholder farming, often the largest agricultural sector in many poor countries of the world, where agricultural stagnation, high population growth, widespread poverty and market imperfections hamper household incentives to adopt conservation practices for the better care of land resources. However, the factors often blamed for causing this apparently excessive deterioration of soil productivity are largely physical categories like overcultivation, overgrazing, overpopulation, deforestation, unskilled irrigation, climatic factors, etc (Tolba, 1987; Nelson, 1988; UNEP, 1992). Research into economic and institutional factors behind any perceived departure between privately and socially optimal soil degradation in the context of smallholder farming is scanty and fragmented. Some available studies on these more subtle factors behind land degradation, however, suggest that the factors often blamed as causes of land degradation tend to be physical manifestations of the underlying market failures (eg. Bojo, 1991). The past focus in many developing countries on superficially perceived causes of land degradation has often led to adoption of misguided policies and failure of soil and water conservation programs.

Although economic analysis of the land degradation issue seems to be getting increasing significance in recent years, the focus on the specific circumstances and problems of peasant agriculture in the developing world has been very limited. Studies into the underlying market failures leading to a Pareto-relevant land degradation externality and analyses of institutional and price incentives for land conservation are very central to the development of farm technologies and formulation of conservation policies and strategies that enhance the sustainability of smallholder farming. Since individual peasant households, whose livelihoods primarily depend on the exploitation of land resources, remain the central decision makers with respect to the management of agricultural land, the study of their behavioral responses to economic incentives is essential for understanding the conditions that lead to depletion of the soil or investment in degradation control measures that conserve the soil.

The purpose of this paper is thus to explore the underlying market failures that lead to the prevalence of the soil degradation problem in the context of peasant agriculture. It also investigates farm-level responses to economic incentives (changes in output prices, input costs, and the real discount rate) to the land users to make investments in land conservation technologies. A dynamic farm-level soil conservation model, with an index of soil fertility as the state variable, and a yield-increasing but soil-degrading input and an alternative input that mitigates the soil-degrading effects of the productive input as the choice variables, is developed. The model is used to study the nature of the private and social intertemporal plan for soil use and the underlying market failures leading to the emergence of the land degradation externality. The conditions under which the smallholder's soil use plan may fail to mimic the socially optimal soil use plan are discussed.

A comparative static analysis of the peasant's soil use problem is also used to examine the economic stimulus to peasant farmers in terms of the choice and intensity of use of the productive and soil-conserving inputs and the impacts on the short and long-term productive capacity of the land. Besides, the use of price-based policy instruments (taxes on soil-degrading productive inputs and subsidies for soil-conserving inputs or a tax on soil loss) for regulation of the soil erosion externality as suggested by the comparative static results of the long run equilibrium is further examined and elaborated using a separate model. The problems and limitations of adopting a regulatory approach to soil conservation in smallholder farming are also discussed.

2. Soil degradation as a social problem

The problem of soil degradation could be examined from the perspective of society as a whole or that of individual land users. The difference in the two perspectives lies in the fact that the social perspective considers all costs and benefits of a given activity, while the analysis from the stand point of the individual user will take into account only those costs and benefits that accrue to the private user. Hence, soil degradation becomes an economic problem when the rate of degradation resulting from private decisions is off the social welfare maximizing path. If social welfare could be increased by curbing the contemporaneous level of soil degradation, then land degradation is excessive and should be reduced. This suggests the deviation between socially and privately optimal behavior in soil conservation.

From the view point of sustainable environmental management, intergenerational equity also suggests that the productive capacity of soil[2] should at least be non-declining. Under conditions in which the natural resource capital could be substituted by man-made capital, depletion of the soil resource could be a socially desirable policy as long as the proceeds from exhausting the resource could be invested in other income generating capital assets which expand the capital stock of future societies (Pearce *et al.*, 1990).

The multifunctionality of natural capital (eg. climate regulation, watershed protection, maintenance of the stock of biological resources, etc.), a feature not shared by man-made capital, however, makes the substitution possibilities limited. Soil as a natural resource is not only an input in the process of production, but is also an essential element of the life support mechanisms upon which all living organisms depend. Above and beyond serving as an essential input in the production of food and fibre, it also plays a vital role in maintaining the stock of essential biological resources (eg. forests). The fact that soil provides non-priced, but essential life support services to the economic system, therefore, precludes complete substitution possibilities between the soil capital and man-made capital. Even if fertility augmenting inputs (eg. fertilizers) may substitute for lost nutrients, costs could be prohibitive and complete replacement of the essential environmental services the natural stock of soil provides may not be possible. Moreover, affluent use of fertilizers, as witnessed in a high input agriculture, could be a major environmental pollutant of agricultural origin. Thus, the productive quality of soil should at least be non-decreasing not only for intergenerational equity concerns but also for maintenance of essential environmental services within a generation.

In order to accommodate sustainability concerns into a formal intertemporal model of soil use and derive the necessary conditions for a socially optimal path, let $q(t)$ denote an index of the productive capacity[3] of the soil in period t, $z(t)$ denote a vector of conventional yield-increasing inputs that deplete soil fertility, $u(t)$ denote alternative soil-conserving and replenishing inputs which could be used to abate the soil-degrading effects of productive inputs $(z(t))$. Therefore, including the time subscripts,[4] the equation of motion for the soil fertility index $q(t)$ could be given by

$$\dot{q}(t) = h(z(t),\ u(t)) \tag{1}$$

where $h_z < 0$, $h_{zz} < 0$,

$h_u > 0,\ h_{uu} < 0,\ h_{uz} = h_{zu} < 0.$

In this specification, h denotes a twice continuously differentiable function of the change in the soil productivity index as a function of the yield-increasing input (z) and the soil-conserving input (u). A similar specification of the transition equation for the soil stock was first proposed by McConnell (1983) and later further developed by Barbier (1990) and LaFrance (1992). Even if soil is generally recognized as a renewable resource, having a transition equation which could be expressed as the difference between the rate of soil formation and rate of soil loss (eg. see McConnell, 1983), the specification given here is general since it assumes both the exogenous addition to the soil base and soil erosion as jointly influenced by the use of variable inputs under the disposal of the farmer. It is, however, important to note that the natural rate of soil genesis also called the tolerable soil loss, expected to equilibrate the natural (geologic) erosion, is very small and is estimated to average only about 1 t per ha per year (Troeh *et al.*, 1991).

The partial derivatives of h are based on the following propositions (in all the dynamic analysis which follows, the notation used for derivatives is h_z for $\partial h/\partial z$ and h_{zz} for $\partial^2 h/\partial z^2$ unless specified otherwise). Since an increasing intensity of production by the use of yield increasing inputs degrades the soil, h_z is negative. The use of the productive input degrades the soil either by exposing it to water and wind erosion which brings selective removal of the most fertile parts of the surface soil (*the soil erosion route*) or direct contamination of the soil which affects its fertility characteristics without a decline in soil depth (*the soil pollution route*) or increased removal of soil nutrients due to high biomass production (*the harvesting route*) or both. The routine farming practices, ploughing and planting, on sloping lands break the structure of the soil and expose it to the ravages of water and wind erosion. Apart from replacing lost nutrients, a vigorous plant growth which establishes after fertilization could provide a protective cover beneficial for protection of the soil from the agents of erosion (Troeh *et al.*, 1991). But, heavy fertilizer use could also accelerate the natural process of soil acidification as nitrates and phosphates leach into the soil profile (Helyar and Porter, 1989; National Research Council, 1989). Surface runoff from irrigation water may cause the loss of soil material through erosion, and the rise in the water table may lead to soil salinization as the dissolved salts are deposited in the root zone (Burch *et al.*, 1987; Troeh *et al.*, 1991).

The soil-conserving inputs protect the soil and hence h_u is positive. Soil-conserving inputs also counteract the soil-degrading effects of productive inputs and reduce the marginal impact of z on the change in soil productivity which stipulates that h_{uz} is negative. The productivity of the soil decreases at an increasing rate with a rise in subsistence demand and greater intensity of production and increasing use of the productive input which suggests h_{zz} to be negative. On the other hand, there exist diminishing returns to the use of the ameliorative input (ie. the effectiveness of the conservation input increases at a decreasing rate) which implies that h_{uu} is also negative.

According to equation (1), soil productivity could be non-decreasing $(\dot{q} \geq 0)$ to the extent that the soil-regenerating and abatement inputs could offset the negative effects of soil-depleting production activities. This also permits some flexibility for a decline in soil depth (as opposed to soil productivity) so long as technological progress^5 allows a rise in soil productivity by use of more efficient soil-replenishing or conservation inputs that would compensate for the deterioration in the productive attributes of the soil. However, it is considered that abatement and fertility enhancing inputs will be ineffective in maintaining soil fertility after the stock of soil depth and other productive characteristics have deteriorated below a certain minimum threshold.

Furthermore, let the period t per hectare production function for a major crop be denoted by

$$f(t) = f(q(t), z(t), u(t)) \tag{2}$$

where, $f_q > 0, f_{qq} < 0,$

$f_z > 0, f_{zz} < 0.$

$f_{qz} = f_{zq} > 0, \text{ and } f(q, z, u) = 0 \text{ for all } q < \bar{q}$.

$f_u > 0, f_{uu} < 0, f_{qu} = f_{uq} > 0, f_{uz} = f_{zu} > 0$ (if conservation is beneficial to production).

$f_u < 0, f_{uu} < 0, f_{qu} = f_{uq} < 0\ f_{uz} = f_{zu} < 0$ (if conservation is counterproductive).

In the specification given in (2), the production function f is assumed to be continuous and twice differentiable and jointly concave in (q, z, u). Below a certain minimum level of soil fertility essential for crop production $(\bar{q})$, the severity of soil degradation has surpassed what could be tolerated with the available technology and such land is considered unalterably lost for crop production at least for a reasonable time frame.

Since soil fertility and productive inputs add to the productivity of the land, the marginal product of soil fertility and the marginal product of the productive input are positive. But there exist diminishing returns in the production technology to the use of all factors (soil, productive inputs and soil-conserving inputs) on a given plot of land. Hence, all the second derivatives of f with respect to each factor has a negative sign. The cross-partials of f with respect to q and z are positive since additional soil quality enriches the crop productivity of the traditional input package, and an increase in these inputs improves the beneficial effect of soil fertility on crop production.

Soil conservation, depending on the type of input package used, may either be counterproductive ($f_u<0$), beneficial to production ($f_u>0$) or somewhat neutral to current production.[6] The cross-partials of f with respect to q and u, and z and u will be positive when conservation boosts output and has immediate benefits to smallholders but will be negative when it diminishes the productivity of the soil and that of the yield increasing input package. LaFrance (1992) develops a dynamic model of farm profit maximization on the assumption that all conservation reduces current productivity of cultivation. Although this may be correct for some conservation packages like construction of physical structures which reduce the effective productive area or cause movement of earth that brings unproductive soil to the surface, several conservation measures either positively contribute to the productivity of the soil and the yield increasing input or leave production unaffected at the worst.

The reduced soil loss and the retention of nutrients, water and soil organic matter after installation of conservation practices could result in higher yields than would have been obtained without conservation (Troeh *et al.*, 1991). For example, in Thailand, upland rice and corn yields from alley cropping and hillside ditches, despite the technologies occupied about one-sixth of the cropland, were at least as high as the farmers' practice in the first year and were even higher in the second year (Aneckasamphant *et al.*, 1991). Additional reviews of experimental results on the beneficial effects of soil conservation on productivity are given in Pimentel *et al.*, (1993), Lutz *et al.*, (1994) and Hobblethwaite (1993).

Furthermore, let the external cost of soil erosion, the extra cost incurred on other economic agents and environmental systems in period t, be denoted by

$$D(t) = D(z(t),\ u(t)) \tag{3}$$

where, $D_z > 0,\ D_u < 0.$

Production inputs and activities increase the off-site costs of soil erosion while adoption of alternative input packages which mitigate the soil-degrading effects of productive inputs have the opposite effect.

The social planner's intertemporal soil use problem is therefore to maximize the present value of net social benefits which could be stated (suppressing the time subscripts) as

$$\underset{(z,\ u)}{\text{Max}} \int_{t=0}^{\infty} \left(pf(q,\ z,\ u) - e_1 z - e_2 u - D(z,\ u)\right) e^{-\rho t} dt \tag{4}$$

subject to the transition equation for soil fertility (1) and an additional sustainability constraint for maintaining the productive potential of agricultural land over an infinite horizon

$$q \geq \bar{q} \tag{5}$$

and the non-negativity constraints $z \geq 0,\ u \geq 0$ and the initial condition $q(0)=q_0$. The parameters $p(t),\ e_1(t),\ e_2(t)$ are the per unit market prices of output, the productive input and the conservation input, respectively. Where markets do not exist for crop outputs or inputs, these prices represent the relevant virtual (shadow) prices in the locality. The real social discount rate or social opportunity cost of capital is denoted by ρ.

When society is concerned about maintenance of the production potential of agricultural land, maximization of (4) subject to (5) is more realistic for agriculture at the aggregate level than at the farm level. However, this depends on society's objective. When the interest of society is to maintain the average production potential of agricultural land, in the sense of Pearce and Atkinson (1993), a weak sustainability constraint is enforced. In this case, depletion of some soils could occur as long as increments in production potential in other areas prevent a decline in the average production potential of the initial area of productive land. In the light of poor marketing facilities and rural infrastructure, the resulting regional disparities in income and mal-distribution of food production potential could, however, make such a policy difficult to implement. If society is interested in maintaining the productive potential of all the available agricultural land at the initial period, (5) should be framed as $q \geq q_0$, and a strong sustainability constraint is enforced (Pearce *et al.*, 1990; Pearce and Atkinson, 1993). The approach used here only prevents total degradation of agricultural lands to retain the option of production.

Most of the sub-Saharan countries of Africa have experienced accelerating population growth, agricultural stagnation and severe environmental degradation. In these countries, one may argue for maintenance of the productive potential of all agricultural land under smallholder farming, not only for the sake of future generations, but also for the well-being of the present generation. Some of these arguments could be summarized as follows:

(a) high rates of land degradation and nutrient depletion (eg. see Stoorvogel and Smaling, 1990) and weak resilience of land which has once been ruined suggest that the available productive land will decline over time.

(b) apart from limited opportunities for intensification due to the general deficiency of land-augmenting innovations, possibilities for extensification are limited or non-existent.

(c) high population growth (3.1% per annum in 1993) coupled with extensive land degradation and lack of land-saving technical change is causing an ever increasing subsistence demand which manifests itself in a worsening poverty, agricultural involution and shortfalls in food production (eg. see Cleaver and Schreiber, 1993; Panayotou, 1994).

Maximization of (4) subject to (1) and (5) is an optimal control problem with an *augmented current value Hamiltonian* (Chiang, 1992) that can be expressed as:

$$\mathcal{L} = pf(q, z, u) - e_1 z - e_2 u - D(z, u) + \lambda h(z, u) + \theta(q - \bar{q}) \tag{6}$$

According to the maximum principle, the optimal trajectories for the control variables z and u and the state variable q and the costate variables λ and θ should satisfy

$$\mathcal{L}_z = pf_z - e_1 - D_z + \lambda h_z \leq 0 \qquad z \geq 0 \qquad z\ (\mathcal{L}_z) = 0 \tag{7}$$

$$\mathcal{L}_u = pf_u - e_2 - D_u + \lambda h_u \leq 0 \qquad u \geq 0 \qquad u\ (\mathcal{L}_u) = 0 \tag{8}$$

$$\mathcal{L}_\theta = (q - \bar{q}) \geq 0 \qquad \theta \geq 0 \qquad \theta(q - \bar{q}) = 0 \tag{9}$$

$$\dot{\lambda} = \rho\lambda - \mathcal{L}_q = \rho\lambda - pf_q - \theta \tag{10}$$

$$\dot{q} = \mathcal{L}_\lambda = h(z,u) \tag{11}$$

plus appropriate transversality conditions.[7] [8] The maximum principle conditions (7)-(11) plus the transversality conditions will be sufficient for the global maximization of the objective functional, the discounted present value of net returns, when $\mathcal{L}$ is concave in (q,z,u) for all t (Mangasarian, 1966), or the current value Hamiltonian maximized subject to $q \geq \bar{q}$ and evaluated at the $z^*(t)$ and $u^*(t)$ path is concave in q for all t (Arrow, 1968) supplemented by a transversality condition $\lim_{t \rightarrow \infty} \lambda(t)e^{-\rho t}[q(t) - q^*(t)] \geq 0$ (Chiang, 1992).

When the control constraint is non-binding in the optimal solution ($z > 0$), (7) suggests that the socially optimal use of the productive input calls for equating its marginal value product to the sum of the per unit cost of the input, the value of the marginal decrease in soil fertility and the marginal external cost arising from the use of the input. When the control constraint is binding, the marginal social benefit from the use of input falls short of its marginal social cost and hence the input must not be used ($z=0$). The costate variable λ has an interpretation of the current value shadow price or marginal unit value of soil fertility. It can also be interpreted as the marginal implicit cost of soil degradation. When the shadow value of of soil fertility increases, the marginal social cost of using the input increases (in a static sense this implies that the marginal social cost curve shifts upwards) and hence the optimal level of z decreases.

The maximum principle condition for the soil ameliorative (conserving) input (8), also warrants a similar interpretation. When the control constraint is non-binding and u has a positive marginal contribution to output, social optimality requires that the sum of u's marginal contribution to production, its contribution to improvement of soil fertility and abatement of spill-over effects of soil erosion should be equated to the marginal cost of the input. When u has a negative marginal contribution to production, (8) stipulates equating the costs in terms of declining production and the cost of the input to the social benefits in terms of a decrease in the external cost of erosion and an increase in soil quality. When the control constraint is binding and the marginal social cost of the conservation input exceeds that of its marginal social benefit, the Kuhn-Tucker conditions ensure complete withdrawal from the use of this input. It is also important to note that a rise in the implicit cost of soil degradation will increase the social benefits of the conservation input, and hence the optimal level of u will increase.

3. Soil degradation as the smallholder's problem

Unlike society at large, which may be interested in maximizing the social present value of net returns from soil use while maintaining the productive potential of the land over time, the smallholder farmer, as an individual, lacks the incentive to account for the off-site costs of her erosive activities in making production decisions. Therefore, the external cost imposed on society, $D(z,u)$, will not enter into the smallholder's net present value maximizing decisions. Thus, the private land user may not take any action to mitigate or arrest the off-site damage inflicted upon other economic agents or environmental systems. This could, for example, be the case when soil erosion originating from one farmer's fields deposits infertile sub-soil sediment[9] on the fields of other farmers. This could reduce its future productivity or damage standing crops. Moreover, uncontrolled run-off originating from the same fields could cause excessive erosion or flooding downstream, or soil sediment washed off the field silts a reservoir or pollutes rivers, lakes and streams.

Individual land users may also lack economic or institutional incentives to maintain the productive quality of agricultural land for future generations. McConnell (1983) argues that when asset markets function smoothly and the land market is perfect (future land prices reflect the productive quality of land) and a strong bequest motive exists, current land users may view the resale value of land as part of the household's income stream. In this case, the user cost of soil erosion will be composed of the marginal contribution of soil quality to the stream of discounted net benefits before selling the land at period *T* and its marginal contribution to its selling value at period *T*. The length of the individual's planning horizon, in this case, should not distort the outcome and individual land users may have the incentive to maintain the productive quality of the land indefinitely. In the case of smallholder farming, capital and land markets could be imperfect or non-existent. Incomplete transferability of rights to land and asset market imperfections may cause divergence between individual and social planning horizons and user costs of soil erosion. The formulation of the smallholder's soil use problem below assumes hereditary rights to land and hence the household maximizes the flow of discounted net returns in perpetuity.

Assuming the wealth maximizing household farm is conscious of the effect of the choice of inputs on soil quality and the resulting effect on soil productivity, the smallholder's intertemporal soil use problem will be to:

$$\underset{(z,\,u)}{\text{Max}} \int_{t=0}^{\infty} \left(pf(q,\,z,\,u) - e_1 z - e_2 u\right) e^{-rt}\,dt \tag{12}$$

subject to (1) and the non-negativity constraints $0 \leq z$ and $0 \leq u$, and the initial condition $q(0)=q_0$. The smallholder's real rate of discount or the rate of time preference is denoted by r. The undiscounted Hamiltonian of maximizing (12) with respect to z and u subject to the above constraints is given by

$$H = pf(q,\,z,\,u) - e_1 z - e_2 u + \lambda h(z,\,u) \tag{13}$$

The maximum principle calls for the following necessary conditions.

$$H_z = pf_z - e_1 + \lambda h_z \leq 0 \qquad z \geq 0 \qquad z(H_z) = 0 \tag{14}$$

$$H_u = pf_u - e_2 + \lambda h_u \leq 0 \qquad u \geq 0 \qquad u(H_u) = 0 \tag{15}$$

$$\dot{\lambda} = r\lambda - pf_q \tag{16}$$

$$\dot{q} = h(z,u) \tag{17}$$

When the control constraint is non-binding in the optimal solution, private optimality requires equating marginal returns from each input to marginal private cost. In the individual household's problem, λ could be interpreted as the current value shadow price of soil fertility or the undiscounted marginal user cost of soil degradation. It represents the increment (decrement) in the current value of net returns to the peasant resulting from a marginal improvement (deterioration) in soil fertility.

As usual, the Kuhn-Tucker conditions require a zero level of use of the input when the non-negativity restriction on the optimal control is binding. It is worthwhile to note that the optimal use of the soil-conserving input u requires equating the sum of the value of its marginal product and the value of its marginal contribution to replenish soil fertility to that of its unit cost. But, when u is unproductive, the peasant equates the value of the marginal contribution in soil fertility improvement to its marginal cost and the value of the marginal decline in output. This implies that the peasant's use of the soil conservation input will be higher when it adds to current productivity of the soil than when it fails to provide immediate livelihood requirements. The static version of this is depicted in Figure 1. While only u_1 levels of the soil-conserving input are used when conservation fails to improve current productivity, this improves to u_2 when it has an immediate yield-increasing effect. If the land user is completely ignoring the user cost of soil, the optimal level of use of the soil-conserving input will be zero when conservation is unproductive and a level less than u_2 will be used when conservation is productive.

4. Market failures and the soil erosion externality

Any disparities between the socially and privately optimal paths of soil use could be discerned from comparison of the necessary conditions for the centralized and decentralized decision makers' problems. If the decentralized profit maximization problem of the private smallholder results in a vector $[z(t), u(t), q(t), \lambda(t)]$ for all t, which differs from the vector which maximizes the social value of net benefits, then soil erosion could be perceived as a social problem the control of which could potentially improve social welfare (depending on associated costs of intervention). In the case where (a) the external costs of soil erosion are absent, and (b) input, output, land and capital markets are perfect, the social and private user cost of soil degradation will be the same, and as McConnell (1983) notes, the private intertemporal path for soil use will mimic the socially efficient path. In such an outcome, the market prices (for inputs and output) reflect social scarcity values, the social and private rates of time preference are one and the same and hence soil erosion will cease to be a social problem since an allocation which results from the decisions made by self-interested private land users will emulate the socially efficient intertemporal plan for soil use.

Although the scale and magnitude of each source of misallocation would depend on time and space, none of the above conditions would hold in the real world. The external damage cost incurred in each period from the use of soil-degrading inputs may occur both directly and indirectly.

(a) agrochemicals carried in overland flow may directly cause pollution of water bodies or damage crops when deposited on the fields of incompatible crops or directly interfere with the biochemical characteristics of the soil in the neighboring fields.

(b) indirectly through their effect on soil erosion, the soil sediment carried in overland flow may cause pollution of ground and surface water, or sedimentation which affects navigation canals and reservoirs, or deposition of infertile sediment on productive agricultural lands.

In industrial agriculture which uses large quantities of agrochemicals and has a well developed non-agricultural sector in the rural areas, the off-site costs of soil erosion tend to be more pronounced than the on-site productivity impacts. For example, for the United States, the estimated off-farm damages from soil erosion of about \$3.2 to 13 billion in 1980 (Clark, 1985) is about six to ten times larger than the on-farm productivity impacts of \$ 0.5 to 1.2 billion in 1983 (Colacicco *et al.*, 1989). In such a case, control of soil erosion is justified largely on accounts of the market failure leading to off-site environmental impacts of soil erosion rather than the concern for maintenance of productive potential of the land for unborn generations (McConnell, 1983; Nowak, 1988).[10]

In the context of peasant farming, particularly in sub-Saharan Africa, the use of external yield-increasing inputs like fertilizer and pesticides is yet at a very low level. The average fertilizer use rate (in terms of nutrients NPK) of the developing countries (excluding China) which in 1988/90 was 62 kg per ha of harvested area is only about half of the average for the developed countries. Sub-Saharan Africa used only about 11 kg per ha and is in general suffering from too little use and excessive nutrient depletion (Stoorvogel and Smaling, 1990; FAO, 1995) rather than overuse. The developing countries also accounted only a fifth of the global consumption of pesticides in the mid-1980s. Their share in the global use of insecticides, fungicides and herbicides is 50%, 20% and 10%, respectively. Again, sub-Saharan Africa consumed only 4% of the developing countries' use of pesticides. Therefore, in peasant farming, application of agrochemicals and inorganic fertilizers, at least in the next two decades, will generally remain below the level which may pose a major pollution problem (FAO, 1995). The low level of use of yield-increasing inputs coupled with underdevelopment of the rural non-farming sector implies that the direct off-site effects of soil-degrading inputs in peasant agriculture may not be very significant. However, one could envisage that the indirect external effects such as sediment pollution of rivers and streams, which serve as sources of drinking water for the vast rural population and their livestock and the associated health impacts, albeit difficult to quantify, could be quite significant. Other effects like downstream flood damages, soil productivity loss and crop damages via the erosion exacerbating effect of production inputs may not also be negligible.

Whenever external costs, costs inflicted on other economic agents, $D(z,u)$, are non-negligible, the social user cost of soil erosion may differ from the private user cost and hence the private user's intertemporal plan of soil use may deviate from the socially optimal plan. This result is consistent with what has been found by Shortle and Miranowski (1987). Hence, as McConnell (1983) shows the private and the social incentives to conserve the soil should not differ when markets are competitive, off-site effects are absent, land markets reflect land quality, and $r=\rho$. However, the presence of external effects in an otherwise perfect market may introduce inefficiency. The deviation between the private and social plan in the presence of external effects implies that the marginal user costs of soil use will also differ. This effect is better explained when soil erosion itself is the control variable as in the McConnell (1983) and Shortle and Miranowski (1987) models rather than the variable inputs used in this analysis. In order to show this effect with less rigor, let us assume that the social and private problems in (4) and (12) only differ due to off-site effects in the former. Since private users will not incorporate off-site effects into their decision calculus, the private implicit cost of eroding the soil (λ_p) captures only the forgone future on-site productivity losses. Since off-site effects are real costs to society that cannot be ignored, the user cost of soil erosion should include both the on-site and off-site costs of using the soil in each period. Since the maximum principle conditions (MPCs) of the two problems will be different in the presence of *D(.)*, let us use ε for MPCs from the social problem. From (7) of the social problem

$$-\lambda^{\varepsilon} h^{\varepsilon}_{z} = pf^{\varepsilon}_{z} - e_{1} - D_{z} \tag{18}$$

From (14) of the private soil use problem we can similarly derive

$$-\lambda h_{z} = pf_{z} - e_{1} \tag{19}$$

Equations (18) and (19) show the social and private on-site user costs of using an erosive input z in each period. Without knowing the relative size of pf^{ε}_{z}, D_z and pf_z (18) and (19) are non-comparable. Intuitively, when the level of z is reduced to internalize the off-site costs, the on-site user cost is likely to be lower in the social problem if $pf^{\varepsilon}_{z} - D_z < pf_z$. This is because when the level of the erosive input (z) is decreased (for a given u) to account for the off-site diseconomy, $pf^{\varepsilon}_{z} > pf_z$, but $-D_z < 0$. In order to compare the social and private user costs in the presence of off-site effects for a given soil quality (q), $pf^{\varepsilon}_{z} - e_1$ in (7) and $pf_z - e_1$ in (14) can be interpreted as marginal period t returns from depleting the soil using the erosive input z. Hence, from (7) and (14), we find that

$$pf^{\varepsilon}_{z} - e_{1} = D_{z} - \lambda^{\varepsilon} h^{\varepsilon}_{z} \tag{20}$$

$$pf_{z} - e_{1} = -\lambda h_{z} \tag{21}$$

As (20) shows, in the social problem, depletion of the soil continues until the marginal returns from using the soil equal the social user cost of eroding the soil (off-site costs plus the on-site user cost of soil erosion) in each period. However, (21) shows that the private farmer will continue eroding the soil only until the returns from using the soil equal the private user costs in each period. Since $-\lambda^{\varepsilon} h^{\varepsilon}_{z}$ and $-\lambda h_z$ are generally different as shown in (18) and (19), (20) and (21) cannot be directly compared. However, when the level of z is reduced (for u constant), the concavity assumption leads to $pf^{\varepsilon}_{z} > pf_z$. Thus, (20) will be larger than (21) (i.e., $D_z - \lambda^{\varepsilon} h^{\varepsilon}_{z} > -\lambda h_z$). In this case, the private user cost of soil will be lower than the social user cost, which indicates that private land use will lead to socially excessive erosion. Assuming that the off-site externality is internalized by using the abatement input u (for z constant), a similar comparison of (8) and (15) indicates that, when $pf^{\varepsilon}_{u} < pf_u$, the level of conservation achieved by a private user will be socially sub-optimal since the private user cannot capture the off-site benefits of using a less-erosive input u. However, these effects need to be verified by solving for the optimal time path of all the variables.

The on-site user cost of soil erosion (λ) also declines with a rise in the discount rate, r (McConnell, 1983; Barbier, 1990; LaFrance, 1992). This effect is difficult to show given the general functional form used that hinders derivation of an explicit time path for $\lambda(t)$. This is because $k = pf_q(q(t), z(t), u(t)) + \theta$ in (10) is generally not a constant unless in the steady state.[11] When the rate of discount (r) is inversely related to the marginal user cost, a higher rate of discount leads to a faster rate of soil depletion. Therefore, to the extent that the private rate of discount (r) differs from the social rate of discount (ρ), the corresponding user costs will vary, and the private soil depletion plan will deviate from the socially optimal plan even in the absence of external costs.[12] Moreover, when the sustainability constraint is binding ($\theta > 0$), for a given rate of discount and soil depth, the social user cost of soil may be larger than the private user cost. In sum, when the costate variable of the farmer's soil use problem fails to accurately reflect the future on-site externality back to the present, optimal intertemporal internalization of the externality may not occur even when off-site effects are minimal. This effect of the discount rate is further explored in 5.2.2.2.

Poverty and capital market imperfections are frequently cited as important factors which influence the discount rate or the rate of time preferences of the smallholder farmers (Perrings, 1989; Pearce *et al.*, 1990; World Bank, 1992; Mink, 1993). For the very poor households who struggle at the verge of subsistence levels of consumption, their day-to-day survival predominates the concern for long-term environmental effects of their current decisions. When their livelihood is threatened, the needy may have no option other than overlooking the future consequences of their current production decisions. Since a high rate of time preference lowers the ability to forgo current consumption to meet long-term income and consumption requirements, the resulting myopic behavior may induce increasing intensification on sloping lands, shortening of fallow periods, overgrazing on pastures or removal of forest cover. Thus, a high subjective discount rate may lead to a rapid resource extraction and low investment to maintain or improve future returns.

There exist strong synergies and causality chains linking poverty, environmental degradation and population growth (WCED, 1987; Von Braun, 1992; Chopra and Delhi, 1992; Mink, 1993;). While worsening poverty compels the poor to act in ways that exacerbate depletion of resources from which the poor wrest their livelihood, environmental degradation perpetuates poverty. Increasing destitution and environmental degradation also provide incentives for larger families (Mink, 1993; Dasgupta and Mäler, 1994). Hence, environmental degradation coupled with high population growth exacerbates the effects of poverty on rate of time preference of the poor. Poor upland peasants, cultivating erodible soils, who risk falling below subsistence levels of consumption, are therefore caught up in a poverty-land degradation-population growth nexus which diminishes the ability to sacrifice current consumption and their incentives to invest in land conservation practices for maintenance of soil quality while compelling excessive extraction of the natural resource "savings".

Capital market imperfections also compound the effects of poverty in affecting the time preference of the poor. Several studies on risk attitudes of smallholder farmers in the developing world, despite substantial heterogeneity, verify that farm households operating in these risky environments are almost universally risk averse (Binswanger (1980) for India; Dillon and Scandizzo (1978) for Brazil; Binswanger and Sillers (1983) for the summary of studies in India, Philippines, Thailand and El Salvador).[13] In so far as outcomes become less certain the further into the future they occur, risk-aversion implies preference for less risky outcomes that occur in the near future. Similarly, when future technology or the effect of erosion on productivity are uncertain, lack of information and the resulting economic insecurity may induce smallholders to discount heavily the long-term benefits of soil conservation.

Access to credit and insurance markets stabilizes consumption over time and has important implications for risk-bearing (Eswaran and Kotawal, 1990). Credit and insurance markets in the rural areas of the developing world, however, tend to be highly fragmented, and institutional sources of consumption credit, in particular, are often non-existent. High transaction costs, imperfect information and associated screening, monitoring and enforcement problems, and the need for a collateral also mean that formal credit institutions often fail to serve the needs of the poor in marginal and inaccessible areas. Informal sources of credit upon which rural households heavily rely, are also characterized by usurious rates of interest, rationing and preference for short-term consumption lending (Stiglitz and Weiss, 1981; Hoff and Stiglitz, 1993; Braverman and Guasch, 1993).[14]

Another factor which may influence the time preference of rural households relates to the security of property rights to land. When insecurity of tenure makes future returns uncertain, rural land users may tend to accelerate the rate of extraction of natural resources. For example, when households perceive a risk of expropriation by the state, they may disregard the future productivity impacts of current decisions which accrue to other future users and attempt to capture all the benefits by expediting exploitation before they lose the right to use the resource. Insecurity of tenure could thus encourage land users to overexploit resources to maximize current benefits. A related issue is the incentive problem of incomplete land rights in making land improvement investments with long payback periods. Even if, rural households perceive sufficient economic incentives to invest in land-augmenting technologies, insecure or incomplete rights to land, which make future returns uncertain (lower expected returns), could discourage adoption of such practices. Tenure insecurity could therefore have an effect of increasing the time preference of the poor and discouraging adoption of land-augmenting technologies.

It should, however, be noted that myopic decision behavior and high rates of time preference may not always be inherent characteristics of the poor (Chambers, 1987; World Bank, 1992). The short-term focus of the poor often results from interactions among policy, institutional and market failures which could corrode the poor's incentives to acquire a long-term view in the face of population growth and increasing land scarcity. The lack of access to credit markets for consumption smoothing in the face of production and market risks, lack of wealth (eg. livestock) which could be dissaved during periods of dearth, misguided development policies designed to extract surplus from the rural sector without sufficient investment to stimulate agricultural growth, insecurity of tenure and incomplete rights to resources, and disintegration of traditional mechanisms of mutual assistance and reciprocity often determine the smallholder's ability to cope with risk and the ability to sacrifice current consumption to meet future needs.

Under the circumstances in which market, institutional and policy incentives exist to ensure livelihood security, poor rural farmers are frequently observed to make sequential investments for maintenance of the productive capacity of their land resources which demonstrates long time horizons (Chambers, 1987; Barbier, 1990; Mink, 1993). Although empirical evidence on the rate of time preferences of smallholder farmers in the rural developing areas is still lacking, measurements made through experimental games with a small sample of poor farmers in rural India resulted in a mean estimated time preference of 35% (Pender and Walker, 1990). The same study reports a slow decline in the rate of time preference as the level of wealth increased (for every 10% rise in net wealth, the relevant rate of time preference waned by 3-7%). Therefore, the time horizon of the poor may gradually increase with a gain in income and livelihood security.

5. Economic incentives for land conservation

In what follows, the smallholder's intertemporal soil use problem will be used to derive farm-level responses to (a) output marketing, (b) input pricing and taxation policies, (c) changes in the scarcity value of soil fertility, (d) changes in the discount rate, and the resulting effects on the long-term productive capacity of the soil. The behavior of the peasant household towards the soil is determined by the impact of the change in soil conditions on the stream of annual net revenues. The changes in household's decision behavior resulting from changes in market and institutional incentives are thus used to simulate and examine behavior towards conservation of the productive capacity of agricultural land over the long run. The analyses of farm-level responses and incentives to land users in relation to the choice of inputs that degrade or conserve the soil to control the long-term productivity loss from soil erosion will be presented in a comparative static framework.

5.1 Comparative statics of the temporary equilibrium

From the solutions of the farmers soil use problem which could be characterized in terms of a temporary equilibrium of the system (Barbier, 1990), one could depict the two controls as a function of output prices, input costs, an index of soil fertility and the shadow value of soil [$y = y(p, e_1, e_2, q, \lambda)$, where $y = z, u$]. In order to carry out the comparative statics of the temporary equilibrium, we need to totally differentiate the maximum principle conditions (14) and (15) which provides (for the detailed algebraic manipulations see Appendix I):

$$J \begin{bmatrix} dz \\ du \end{bmatrix} = \begin{bmatrix} -pf_{zq}dq - f_z dp + de_1 - h_z d\lambda \\ -pf_{uq}dq - f_u dp + de_2 - h_u d\lambda \end{bmatrix} \tag{22}$$

Where **J** is the Jacobian matrix given by

$$J = \begin{bmatrix} pf_{zz} + \lambda h_{zz} & pf_{zu} + \lambda h_{zu} \\ pf_{uz} + \lambda h_{uz} & pf_{uu} + \lambda h_{uu} \end{bmatrix} = \begin{bmatrix} H_{zz} & H_{zu} \\ H_{uz} & H_{uu} \end{bmatrix}$$

Thus, the Jacobian matrix **J** is nothing but the matrix of the second-order partial derivatives of the current value Hamiltonian given by (13) with respect to the control variables z and u. According to the maximum principle, the second-order conditions for maximization of H with respect to the controls z and u demand the determinant of **J** to be positive ($|\mathbf{J}| > 0$). It is also important to note that by the propositions given in (1) and (2), H_{zz} and H_{uu} are negative. When soil conservation adds to the short-term productivity of the soil, the cross-partials of f with respect to z and u will be positive and $H_{zu} = H_{uz}$ will not have a definite sign on theoretical grounds. But, when conservation reduces the short-term productivity of the soil, $H_{zu} = H_{uz}$ will definitely be negative. Applying Cramer's rule to (22), and keeping all the parameters unchanged except the one under investigation, the comparative static derivatives of z and u with respect to the parameters (p,e_1,e_2,q,λ) can be obtained easily.

The comparative static derivatives of the endogenous variables z and u with respect to the exogenous variables will be given in relation to two alternative assumptions regarding the short-term effects of conservation on crop output: (a) when the conservation input package helps to boost crop yields, and (b) when the conservation input package is counterproductive to the soil and the yield-increasing input package.

i) The conservation input package increases output[15]

The short run responses of the choice variables to the parameters of the problem (summarized in Table 1) will be

$$\text{(a)} \quad \frac{\partial z}{\partial p} = \frac{-f_z(H_{uu}) + f_u(H_{zu})}{|J|} \gtrless 0 \tag{23}$$

In equation (23), the first term in the numerator is positive since $H_{uu} < 0$. But, the second term could be positive when H_{zu} is positive (ie. $pf_{zu} > \lambda h_{zu}$ in absolute value). This implies that the use of the yield-increasing input will increase with a rise in the relative price of the product when the gain in the productivity of z from the use of the soil conservation input package exceeds the resulting increase in soil degradation. Thus, the use of the productive input increases with a rise in the relative price of output when its contribution to production more than offsets its negative contribution to worsening soil erosion and deterioration in soil fertility. Conversely, when the improvement in the productivity of the yield-increasing input from the use of the soil conservation input package fails to balance the deterioration in the effectiveness of the soil-conserving input, the use of the yield increasing input might decline despite the rise in output price.

$$\text{(b)} \quad \frac{\partial u}{\partial p} = \frac{-f_u(H_{zz}) + f_z(H_{uz})}{|J|} \gtrless 0 \tag{24}$$

Since $H_{zz} < 0$, the first term in the numerator of (24) is always positive. As in (23), H_{uz} could be positive when $pf_{uz} > \lambda h_{uz}$ in absolute value. This suggests that a rise in the product price could lead to an increase in soil conservation when an increment in the productivity of the soil conservation input emanating from the use of the productive input dominates the resulting deterioration in the effectiveness of the conservation input package. Provided the boost in the productivity of the soil-conserving input more than offsets the soil-degrading impact of the productive input package and the two inputs are complementary in production, a rise in the output price is an incentive for more conservation. However, adoption of the soil-conserving input might decline with a rise in product price when the use of the productive input leads to more erosion than it adds to the productivity of the soil-conserving input.

$$\text{(c)} \quad \frac{\partial z}{\partial q} = \frac{-pf_{zq}(H_{uu}) + pf_{uq}(H_{zu})}{|J|} \gtrless 0 \tag{25}$$

The first term in (25) is positive since $H_{uu} < 0$. The second term, however, could be positive only when H_{zu} is positive. Thus, in the near term, the intensity of use of the productive input increases with an improvement in the productive capacity of the soil when the soil conservation input contributes more in terms of enhancing the productivity of the yield-increasing input than the resulting increase in soil degradation. In the reverse case in which H_{zu} is negative, there is a possibility that the intensity of use of the productive input might decline despite a rise in the productive capacity of the soil.

(d) $$\frac{\partial u}{\partial q} = \frac{-pf_{uq}(H_{zz}) + pf_{zq}(H_{uz})}{|J|} \gtrless 0 \qquad (26)$$

The first term in the numerator of (26) is positive since $H_{zz} < 0$. But, the second term will be positive only when $H_{uz} > 0$. Then, the use of the conservation input package will unambiguously increase despite the rise in the productive capacity of the soil. This indicates that when an increment in the productivity of the ameliorative input from the use of the productive input package exceeds the associated increase in soil degradation or the decline in the effectiveness of conservation, the intensity of use of the soil conservation input increases with an increase in the fertility of the soil. The possibility that smallholders could increase the conservation effort in the face of increasing soil productivity is a seemingly perverse behavior. However, this is mainly because the soil-conserving input is, by formulation, an "overlap technology" which plays a dual purpose of conserving the soil by mitigating the soil-degrading impacts of the productive input package while simultaneously serving to boost the productivity of the soil. The only case in which the use of the conservation input might decline with an improvement in soil fertility occurs when the increment in yield is more than offset by the associated increase in soil degradation from the use of the productive input.

(e) $$\frac{\partial z}{\partial \lambda} = \frac{-h_z(H_{uu}) + h_u(H_{zu})}{|J|} \gtrless 0 \qquad (27)$$

The first term in the numerator of (27) is negative. If the second term is also negative, the intensity of use of the productive input unambiguously decreases when the user cost of soil degradation increases. This signifies that when the benefits in terms of an increment in output from the use of the productive input is less than the associated cost in terms of an increment in soil degradation, the intensity of use of the soil-degrading input will decline with a rise in the marginal user cost of soil. In the case where the input's contribution to increment in yield is more than the resulting increase in soil erosion, the intensity of use of the soil-degrading input might increase with a rise in the scarcity value of soil fertility. This perverse behavior, however, arises only when the second term in the numerator of (27) exceeds the first term.

(f) $$\frac{\partial u}{\partial \lambda} = \frac{-h_u(H_{zz}) + h_z(H_{uz})}{|J|} \gtrless 0 \qquad (28)$$

The first term in the numerator of (28) is positive. When the second term is also positive ($H_{uz} < 0$) the use of the soil conservation input will unambiguously increase with a rise in the shadow value of the soil. This also implies that when the costs in terms of an increase in soil degradation resulting from the use of the productive input exceed the benefits in terms of increment in the productivity of the soil conservation input, the soil conservation effort will increase with a rise in the cost of soil erosion. In the converse case in which productivity improvement benefits exceed the associated costs of soil degradation ($H_{zu} > 0$), the use of the soil conservation input might decline despite an increase in the user cost of soil degradation.

$$\text{(g)} \quad \frac{\partial z}{\partial e_1} = \frac{H_{uu}}{|J|} < 0 \tag{29}$$

Since equation (29) is unambiguously negative, a rise in the cost of the productive input will discourage its use.

$$\text{(h)} \quad \frac{\partial u}{\partial e_1} = \frac{-H_{uz}}{|J|} \gtrless 0 \tag{30}$$

This suggests that the use of the soil-conserving input will unambiguously increase with a rise in the price of the productive input when $H_{uz} < 0$. In that case, the effect of z on increasing the marginal product of u is less than the resulting soil degradation from the use of this input. Thus, a rise in the cost of the yield-increasing input will induce more conservation in the short-run. This could, for example, be the case where peasants cognizant of erosion's impact on productivity tend to increase the soil conservation effort when higher input (eg. fertilizer) prices deter the use of the productive input that would have prevented yields from declining in the face of worsening soil erosion. In the case where the productive input increases the marginal productivity of the conservation input more than its effect on soil degradation ($H_{uz} > 0$), the conservation effort will decrease with a rise in the cost of the yield-increasing input.

$$\text{(i)} \quad \frac{\partial u}{\partial e_2} = \frac{H_{zz}}{|J|} < 0 \tag{31}$$

As equation (31) indicates, adoption of the soil conservation input declines with a rise in its market price. Thus, a rise in the cost of conservation is an obvious disincentive to conserve the productive capacity of land.

$$\text{(j)}\quad \frac{\partial z}{\partial e_2} = \frac{-H_{zu}}{|J|} \gtrless 0 \qquad (32)$$

The most intuitive case implied by (32) is when the intensity of use of the yield-increasing input increases with a rise in the cost of conservation ($H_{zu} < 0$). This may for example occur when rural households tend to increase the use of fertilizer or the intensity of labor use in cultivation to sustain production levels in the face of excessive nutrient depletion when higher costs deter adoption of the conservation input. In the reverse case where the contribution of the soil-conserving input in terms of enhancing the productivity of the yield-increasing inputs is larger than the associated increase in soil degradation ($H_{zu} > 0$), a rise in the cost of conservation will discourage the use of yield-increasing inputs. In the latter case, soil mining will be a logical short-term production strategy as higher costs make conservation uneconomical and households engage in farming without compensating for lost nutrients.

ii) The conservation input package decreases output

In the case where conservation reduces short-term crop yields, the cross-partials of f and h with respect to z and u have the same sign, and $H_{uz} = H_{zu} < 0$. Hence, the comparative static derivatives obtain unambiguous results. The general short run effects are straightforward and are summarized in Table 2. The comparative static derivations are given in Appendix II.

However, it should be noted that the same comparative static results could be obtained when the conservation input only plays the role of mitigating the soil-degrading effects of the yield-increasing input. In such a case where conservation has no effect on crop yield, it will not be an argument of the production function given in (2) but will remain as a neutral input to production which only influences the periodic change in soil fertility.[16]

In general, when soil conservation entails a reduction in output, in the short term, a rise in the price of output, an improvement in the fertility of the soil, a decrease in the cost of the productive input, and an increase in the cost of the conservation input encourage more intensive use of the productive input over that of the soil-conserving input. On the other hand, a rise in the cost of soil erosion, a decrease in the productivity of the soil, a decrease in the cost of conservation and an increase in the cost of yield-enhancing inputs tend to favour the use of the soil conservation input over the soil-degrading but productive input package.

5.2 Comparative statics of the steady state

Analysis of the long-term intertemporal equilibrium or the steady state of the smallholder's soil use problem also provides the direction of change in the long-term soil fertility in response to changes in the parameters of the problem. The comparative statics of the steady state will help simulate peasant behavior in response to changes in market and institutional incentives and the resulting changes in farming practices that influence soil fertility in the long run. This will also have important implications for policy intervention to encourage a wider diffusion of conservation technologies in areas of different agricultural potentials. Analytical results of the general functional form used so far will be presented with a qualitative analysis based on a phase-diagram.

5.2.1 Phase-diagram analysis

From the maximum principle conditions for the peasant household's problem given in (16) and (17), at the stationary state, the transition equations for q and λ defined in the λq space can be given by

$$\dot{\lambda} = \psi(\lambda, q) = r\lambda - pf_q[z(\lambda, q), u(\lambda, q), q] = 0 \qquad (33)$$

$$\dot{q} = \phi(\lambda, q) = h[z(\lambda, q), u(\lambda, q)] = 0 \qquad (34)$$

Since there is no explicit t argument in the current value maximum principle conditions, the resulting autonomous system enables a qualitative analysis of the intertemporal equilibrium by a phase-diagram. In order to depict the $(\dot{q} = 0, \dot{\lambda} = 0)$ isoclines in the λq space, we need to know the relationship between λ and q in the stationary state given in (33) and (34). As shown in Table 2, the comparative static results with respect to the two controls obtain unambiguous signs when conservation reduces the productivity of the soil and hence comparative static results of the steady state also obtain definite signs. However, given the general functional form used in this analysis, the slope of the required isoclines and the signs of some comparative static results cannot be determined when conservation adds to the productivity of the soil. In such a case, in order to identify the conditions that will allow the knowledge of the signs of the long run responses of the soil stock to changes in the problem parameters, the following qualifications which generally reflect the type of land conservation options currently available to peasant households in the rural areas of the developing world are used.

(a) the positive contribution of conservation in improving the marginal product of the yield-increasing input is more than offset by an associated increase in soil erosion (ie. $H_{zu} = H_{uz} < 0$).

(b) not withstanding $H_{zu} = H_{uz} < 0$, an increase in soil fertility favours the use of the yield-increasing input ($z_q > 0$) but discourages investment in land conservation activities ($u_q < 0$).

(c) the soil is more responsive to the productive input than to the soil-conserving input, hence $f_{qz} > f_{qu}$.

These assumptions, which are plausible and more intuitive in the context of smallholder farming in areas like the highlands of Ethiopia, will help extend the theoretical analysis to the case of a productive land conservation.

Given these assumptions, the partial derivatives of the costate variable λ with respect to the productive capacity, q, evaluated at constant q and λ over time can be written as:

$$\left.\frac{d\lambda}{dq}\right|_{\dot{q}=0} = \frac{-\phi_q}{\phi_\lambda} = \frac{-h_z z_q - h_u u_q}{h_z z_\lambda + h_u u_\lambda} > 0 \tag{35}$$

$$\left.\frac{d\lambda}{dq}\right|_{\dot{\lambda}=0} = \frac{-\psi_q}{\psi_\lambda} = \frac{p(f_{qz} z_q + f_{qu} u_q + f_{qq})}{r - p(f_{qz} z_\lambda + f_{qu} u_\lambda)} < 0 \tag{36}$$

When conservation is productive, the slope of the $\dot{\lambda} = 0$ isocline will be negative when $f_{qu} u_q + f_{qq} > f_{qz} z_q$ in absolute value and $r - f_{qz} z_\lambda > f_{qu} u_\lambda$. When conservation is unproductive, the denominator of (36) will always be positive, and the sign of the equation will be negative when $f_{qq} > f_{qz} z_q + f_{qu} u_q$ in absolute terms. Given these qualifications, the signs of the slopes of the two isoclines given by (35) and (36) are sufficient to depict the intertemporal equilibrium on a phase diagram as shown in Figure 2. Besides, in order to know the intertemporal movement of λ and q with respect to the steady state we need to know

$$\frac{\partial\dot{\lambda}}{\partial\lambda} = r - p f_{qz} z_\lambda - p f_{qu} u_\lambda > 0 \tag{37}$$

$$\frac{\partial \dot{q}}{\partial q} = h_z z_q + h_u u_q < 0 \qquad (38)$$

When conservation is productive, (37) will be positive by assumption (c) and if $z_\lambda > u_\lambda$. When conservation is unproductive, equation (37) and (38) will have a definite sign as given. Hence, the directional arrows and the configuration of the phase paths (streamlines) sketched with the help of (37) and (38) jointly determine the dynamic movement of λ and q from any conceivable initial point, and the steady state (E) of the peasant's soil use problem could be characterized by a saddle point equilibrium. If the initial soil fertility index is higher than the steady state level, the optimal strategy for the smallholder is to deplete the soil over time until its shadow value rises. If the initial soil fertility index happens to lie on the stable branch, the long run equilibrium will be established at a level which corresponds to E. If the initial soil fertility index is less than the steady state level, the optimal trajectory for soil fertility index will tend to increase over time, and if it happens to lie on the stable branch, the steady state equilibrium will again be established at a level which corresponds to E.

Local stability analysis

As depicted in Figure 2, the two phase trajectories (streamlines), labeled stable branches, directly and consistently lead towards the intertemporal equilibrium at E, while all other streamlines lead away from this equilibrium either directly from the initial point or turn away from it eventually.[17] Thus, the intertemporal equilibrium of the dynamic soil use problem could be designated by a saddle point. Since there is no way to arrive at any target level of the state variable when the equilibrium is characterized by an unstable node or focus, the saddle point equilibrium, with a target that is attainable with specific rules given by the maximum principle and transversality conditions, very well fits the general framework of the dynamic optimization problem.[18] Given the basic assumptions of the model, a local stability analysis confirms that the steady state at E is locally a saddle point (see Appendix III).

5.2.2 Comparative static analysis

Once the steady state of the system and the directional movement of the two variables λ and q has been sketched in a phase diagram, it could further be used to analyze the results of the comparative static derivatives of the steady state. The purpose is to determine the intertemporal movement of the steady state fertility index of the soil stock as a response to changes in output prices, input costs, the rate of time preference, and the intensity of labor use in cultivation/conservation through a qualitative analysis of the comparative statics of the long-term equilibrium. In order to simplify the analysis in the following sections let us redefine (33) and (34) as $\dot{\lambda} = \psi(\lambda, q, p, r, e_1, e_2)$ and $\dot{q} = \phi(\lambda, q, p, r, e_1, e_2)$, respectively. A summary of the comparative static results of the steady state equilibrium for the unambiguous case in which conservation is unproductive to the soil is given in Table 3.

5.2.2.1 Effects of a change in output price.

i) Conservation is counterproductive:

The effect of the change in the relative price of output on the long-term soil fertility status could be seen from the relative shifts in the $\dot{\lambda} = 0$ and $\dot{q} = 0$ isoclines in the λq plane.

$$\left.\frac{\partial\lambda}{\partial p}\right|_{\dot{\lambda}=0} = \frac{f_q + f_{qz}z_p + f_{qu}u_p}{\psi_\lambda} \gtrless 0 \tag{39}$$

$$\left.\frac{\partial\lambda}{\partial p}\right|_{\dot{q}=0} = \frac{-h_z z_p - h_u u_p}{\phi_\lambda} \gtrless 0 \tag{40}$$

When conservation is unproductive to the soil, both (39) and (40) are positive, and the two isoclines shift up in the λq plane. In this case, the long run shadow value of soil quality λ will increase due to the stimulus on current production and an increase in soil degradation resulting from increased intensification as a response to higher product prices. The long-term effect on soil productivity, however, depends on the magnitude of the relative shifts in the two isoclines.[19] When the negative effect on soil erosion of a rise in output price exceeds the positive effect on crop production $((-h_z z_p - h_u u_p)/\phi_\lambda > (f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda)$, the $\dot{q}=0$ isocline shifts up more than the $\dot{\lambda}=0$ isocline, and the long run productive capacity of the soil decreases. In the opposite case, in which the positive effect on production exceeds the negative impact on soil erosion $((-h_z z_p - h_u u_p)/\phi_\lambda < (f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda)$, the $\dot{\lambda}=0$ isocline shifts up more than the $\dot{q}=0$ isocline, and the steady state soil quality increases. When the effect on productivity is balanced by the effect on soil quality, the two isoclines will shift up by a similar magnitude and hence the long run fertility of the soil will be maintained.[20]

This has an important implication for soil quality differentials in different agroecological zones and farming systems. On highly erodible soils with low fertility status where the impact of the productive input on soil erosion will be higher than its contribution to production, a rise in the product price will tend to lower the long run productive potential of the land. On less erodible and high quality soils, the effect on production of the productive input may exceed or balance the negative effect on soil erosion. On such soils a rise in the product price may provide an economic incentive for improvement or maintenance of the long-term fertility status of the soil.

ii) Conservation is productive:

Although the denominators in (39) and (40) are positive by (35) and (36), given the general function used, the two equations could not obtain a definite sign when conservation is productive to the soil. From our previous analysis, z_p and u_p will be positive when $H_{zu}=H_{uz} > 0$. Since this has been excluded by our basic assumptions, we cannot be certain of the signs of z_p and u_p and hence the price effect on the steady state soil fertility index and the cost of soil erosion, in this case, is theoretically indeterminate. Different price effects emerge according to the magnitude and directional shift in the two isoclines in the λq plane. Four possible scenarios are considered below.

(a) The $\dot{\lambda} = \dot{q} = 0$ *isoclines shift up*

This may occur when a rise in output price favours the use of the productive input, but discourages the use of the soil-conserving input, both (39) and (40) are positive, and the two isoclines shift up in the λq plane. The resulting effects on the steady state soil fertility and cost of the soil erosion are similar to that for the case of unproductive conservation.

(b) The $\dot{\lambda} = \dot{q} = 0$ *isoclines shift down*

In relation to (39) and (40), this could happen when the two equations are negative. Although unlikely, such a case may occur when a rise in the relative price of output discourages the use of the productive input, but favours the use of the conservation input. The reduced pressure on the soil resulting from a decrease in the intensity of production will lower the implicit cost of soil erosion in the long run. But the net effect on the steady state soil fertility status will again depend on the positive effect from reduced soil degradation and the impact on soil productivity. In the case where the impact on production exceeds the positive effect on reducing soil erosion $((f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda > (-h_z z_p - h_u u_p)/\phi_\lambda)$, the down-ward shift in the $\dot{\lambda}=0$ isocline will be larger than the same shift in $\dot{q}=0$ isocline, and the long-term productive capacity of the soil declines. When the beneficial effect of the rise in output price on reducing soil erosion exceeds that of the impact on soil productivity $((-h_z z_p - h_u u_p)/\phi_\lambda > (f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda)$, the $\dot{q}=0$ isocline shifts down more than the $\dot{\lambda}=0$ isocline, and the steady state soil quality will improve. In the case where the effect on soil erosion and production counterbalance, the steady state soil fertility will remain unchanged.

(c) The $\dot{q}=0$ *isocline shifts up, while the* $\dot{\lambda}=0$ *isocline shifts down*

This may occur when a rise in output price encourages the use of the productive input but *very strongly* discourages the use of the soil conservation input. The long run effect on soil fertility is unambiguously negative since the undesirable effect on soil degradation outweighs the beneficial impact on increasing the short-term soil productivity. The effect on the long run cost of soil erosion (λ) will, however, depend on the relative magnitude of the negative effect on soil degradation and the impact on productivity. When the effect on soil degradation exceeds the effect on soil productivity $((-h_z z_p - h_u u_p)/\phi_\lambda > (f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda)$, the $\dot{q}=0$ isocline shifts up more than the downward shift in the $\dot{\lambda}=0$ isocline, and the long-term cost of soil degradation will increase. When the effect on production exceeds the associated increase in soil degradation $((f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda > (-h_z z_p - h_u u_p)/\phi_\lambda)$, the $\dot{\lambda}=0$ isocline shifts down more than the up-ward shift in the $\dot{q}=0$ isocline, and the long-term cost of soil erosion will decrease.

(d) The $\dot{\lambda}=0$ *isocline shifts up, while the* $\dot{q}=0$ *isocline shifts down.*

This may result when a rise in the price of output *very strongly* favours the use of the soil-conserving input while it discourages the use of the productive input. A reduction in the use of the soil-degrading input with increasing effort to conserve the soil will unambiguously improve the long-term productive potential of the land. The effect on the shadow value of soil will, however, depend on the relative magnitude of the positive effect on curbing soil degradation and the impact on soil productivity. When the impact on soil productivity outweighs the beneficial effect on abating erosion $((f_q + f_{qz}z_p + f_{qu}u_p)/\psi_\lambda > (-h_z z_p - h_u u_p)/\phi_\lambda)$, the $\dot{\lambda}=0$ isocline shifts up more than the down-ward shift in the $\dot{q}=0$ isocline, and the long run shadow value of the soil will increase. Inversely, when the beneficial effect on controlling soil degradation outweighs the impact on soil productivity $((-h_z z_p - h_u u_p)/\phi_\lambda > (f_q + f_{qz} z_p + f_{qu} u_p)/\psi_\lambda)$, the $\dot{q}=0$ isocline shifts down more than the up-ward shift in the $\dot{\lambda}=0$ isocline, and the steady state shadow value of soil will decrease.

5.2.2.2 Effect of a change in the smallholder's discount rate

The general effect of a change in the peasant's subjective rate of time preference or the discount rate on the time path of the user cost of soil erosion has been previously discussed. Further insights on the effects of the peasant's discount rate on her decision to use productive and soil-conserving inputs and the resulting impact on the long-term productive capacity of the soil could be gained from

$$\left.\frac{\partial\lambda}{\partial r}\right|_{\dot{\lambda}=0} = \frac{-\lambda}{\psi_\lambda} < 0 \qquad (41)$$

This indicates that the permanent increase in the peasant's discount rate shifts the $\dot{\lambda}=0$ isocline down in the λq plane, while the $\dot{q}=0$ isocline will remain unchanged. Hence, both the steady state implicit cost of soil erosion and the fertility index will decrease unambiguously regardless of the effect of conservation on production. Consistent with my previous conjecture, a rise in the peasant's discount rate reflects a strong preference to meet short-term livelihood requirements, which may in turn compel the household to adopt a myopic behavior that discourages investment in land conservation. The combined effect will lower the long-run user cost of soil erosion and the insufficient concern for future impacts of soil degradation will induce more erosion in every period.

An increase in the peasant's discount rate may also reflect the market rates of borrowing capital or the costs of credit available to the household. In the case of many rural areas of developing countries, where credit markets are highly fragmented and dominated by informal sources of credit extending short-term loans at high cost, poor rural households dependent on such sources may discount future consumption and income at the same high rates which reflect the opportunity cost of borrowing capital. Besides, lack of credit institutions, which provide a long-term investment credit, militates against the longer gestation period required for investments in land conservation techniques like establishment of terraces or agroforestry systems. In such circumstances, peasants may be cognizant of the productivity impacts of soil erosion but lack the necessary means to avert the process of soil degradation. The implication is that provision of medium-to-long-term credit and strategies for poverty alleviation and improvement of livelihood security may help lower the discount rate and reduce the pressure to trade off lower future income for greater present consumption. Coupled with other suitable policies, this is likely to help stimulate land-conservation investments.

5.2.2.3 The effect of a change in the cost of conservation

i) Conservation is counterproductive:

When conservation reduces the productivity of the soil, the comparative static derivatives will obtain a definite sign and the effect of a change in the cost of the soil-conserving input could be seen from

$$\left.\frac{\partial\lambda}{\partial e_2}\right|_{\dot{\lambda}=0} = \frac{pf_{qz}z_{e_2} + pf_{qu}u_{e_2}}{\psi_\lambda} > 0 \qquad (42)$$

$$\left.\frac{\partial\lambda}{\partial e_2}\right|_{\dot{q}=0} = \frac{-h_z z_{e_2} - h_u u_{e_2}}{\phi_\lambda} > 0 \qquad (43)$$

Since the denominators in (42) and (43) are positive by (35) and (36), both the $\dot{\lambda}=0$ and $\dot{q}=0$ isoclines will shift up in the λq space. The rise in the cost of conservation will make the conservation effort increasingly expensive to the rural poor, and the cost of soil degradation will rise unambiguously. The ultimate effect on soil fertility will, however, depend on the strength of the effects on soil erosion of an increase in the price of the conservation input and the impact on soil productivity. When the negative impact on soil erosion is more pronounced than the positive impact on soil productivity $((-h_z z_{e_2} - h_u u_{e_2})/\phi_\lambda > (pf_{qz}z_{e_2} + pf_{qu}u_{e_2})/\psi_\lambda)$, the upward shift in the $\dot{q}=0$ isocline will be larger than the same shift in the $\dot{\lambda}=0$ isocline, and the steady state productive capacity of the soil will decrease. This suggests that on highly erodible and poor quality soils, where the negative impact of production inputs on soil erosion may exceed the boost in the marginal productivity of the soil from the use of cultivation and soil conservation (when it is productive) inputs, a rise in the cost of soil conservation will tend to lower the long-term productive potential of agricultural land. The intent of this result in the light of land conservation policy, in farming systems based on highly erodible and infertile soils, is that subsidization of the soil-conserving input is desirable to encourage the rural poor to invest in land conservation practices. Alternatively, it also implies that a shift to other high value crops or to new varieties which provide higher yields on such soils may help promote adoption of conservation practices.

On the other hand, when the effect on soil productivity overshadows the effect on increasing soil erosion $((pf_{qz}z_{e_2}+pf_{qu}u_{e_2})/\psi_{\lambda}>(-h_z z_{e_2}-h_u u_{e_2})/\phi_{\lambda})$, the upward shift in the $\dot{\lambda}=0$ isocline will be larger than the same shift in the $\dot{q}=0$ isocline, and the steady state productive capacity of the soil will increase. This also insinuates that in areas where the increment in soil productivity resulting form the use of productive (and soil-conserving) inputs exceeds or offsets the effect on soil erosion, the long-term productive potential of the soil may increase. This could, for example, be the case in farming systems with highly productive and less erodible soils or when production systems are based on highly valued but less erosive tree crops. Better off households, growing high value crops or operating on soils where returns to investment are high, may afford to make soil conservation investments. This suggests that where peasant households have sufficient economic incentives and the capacity to invest in conservation practices, they could take the necessary precautions against soil erosion without subsidies for soil-conserving inputs.

ii) Conservation is productive:

When conservation adds to the productivity of the soil, the numerator in (42) will not have a definite sign. In the case where $pf_{qz}z_{e_2}>pf_{qu}u_{e_2}$ in absolute terms, the $\dot{\lambda}=0$ isocline will still shift upwards and the result will be the same as that for unproductive conservation. But when $pf_{qz}z_{e_2}<pf_{qu}u_{e_2}$ in absolute terms, the two isoclines will shift in opposite directions. In such a case, the steady state soil fertility level will decrease unambiguously but the effect on the user cost of soil will depend on the relative shift in the two isoclines. When the effect on soil degradation exceeds the effect on production, the upward shift in the $\dot{q}=0$ isocline will be more than the downward shift in the $\dot{\lambda}=0$ isocline and the cost of the soil erosion will

increase. In the reverse case where the effect on production dominates the effect on soil degradation, the downward shift in the $\dot{\lambda}=0$ isocline will be larger than the upward shift in the $\dot{q}=0$ isocline and the steady state marginal user cost of the soil will decrease.

5.2.2.4 The effect of a change in the cost of the productive input

i) Conservation is counterproductive:

The effect of a change in the price of the productive input on the long-term shadow value and productive capacity of the soil could be seen from

$$\left.\frac{\partial\lambda}{\partial e_1}\right|_{\dot{\lambda}=0} = \frac{pf_{qz}z_{e_1} + pf_{qu}u_{e_1}}{\psi_\lambda} < 0 \tag{44}$$

$$\left.\frac{\partial\lambda}{\partial e_1}\right|_{\dot{q}=0} = \frac{-h_z z_{e_1} - h_u u_{e_1}}{\phi_\lambda} < 0 \tag{45}$$

When conservation reduces the productivity of the soil, an increase in the cost of the yield-increasing input will cause a downward shift in both the $\dot{\lambda}=0$ and the $\dot{q}=0$ isoclines in the λq space. Because of the reduced demand from the soil from current production, and reduced soil degradation resulting from the rise in the cost of the yield-increasing input, the long run shadow value of the soil will decline. The effect on the long run soil fertility level will depend on the relative magnitude of the positive effect on reducing soil erosion and the impact on soil productivity. When the positive effect on curtailing soil degradation dominates the effect on soil productivity $((-h_z z_{e_1} - h_u u_{e_1})/\phi_\lambda > (pf_{qz}z_{e_1} + pf_{qu}u_{e_1})/\psi_\lambda)$, the downward shift in the $\dot{q}=0$ isocline will be larger than the same shift in the $\dot{\lambda}=0$ isocline, and over the long haul, the productive capacity of the soil will increase. In the reverse case where the negative effect on soil productivity outshines the positive effect on curbing soil erosion $((pf_{qz}z_{e_1} + pf_{qu}u_{e_1})/\psi_\lambda > (-h_z z_{e_1} - h_u u_{e_1})/\phi_\lambda)$, the downward shift in the $\dot{\lambda}=0$ isocline will be larger than the same shift in the $\dot{q}=0$ isocline, and the steady state productive capacity of the soil will deteriorate.

This result also carries different implications for the success of soil conservation programs in farming systems which differ in soil quality and the type of crops grown. In areas where the soil is (i) highly erodible, and (ii) less responsive to the use of yield-increasing inputs and conservation practices, a rise in the cost of the productive input tends to improve the fertility of the soil in the long run. The reason is that when the cost of external yield-increasing inputs proves to be uneconomical, rural households resort to cropping practices and locally available inputs that will conserve the soil. Moreover, it also points to the need for taxing the soil-degrading input and removal of input subsidies (eg. fertilizer subsidies) which artificially lower the user cost of soil erosion to the farmer by increasing the short-term productivity of the soil. Massive applications of subsidized fertilizer on poor quality and highly erodible soils may boost the short-term returns from the soil, but disguise the effect of erosion on productivity and send wrong signals about current user cost of soil erosion to the smallholder. An artificial increase in the profitability of the soil through heavy applications of subsidized fertilizer may thus have a blinding effect and obstruct the land user from investing in erosion-control and conservation practices.

Nonetheless, despite the economic justification for removal of input subsidies, several exogenous factors not captured in this model, like high fertilizer prices following devaluation of over-valued currencies, lack of credit facilities and cost-effective conservation technologies with immediate economic benefits to the rural poor, may imply that the long run soil productivity index may deteriorate rather than improve following a tax on productive inputs or removal of input subsidies. Besides, locally available soil replenishing inputs may have high opportunity costs. For example, high demand for animal feeding of crop residues or animal manure for generating household energy, as in the Ethiopian highlands, could strongly compete for the use of these resources for replenishing soil fertility. In such circumstances, peasants may again be very well aware of the rising user cost of soil erosion but in lack of the necessary means for curbing the problem they may simply resort to farming practices that deplete the soil and drastically lower the long run productive potential of the land.

In areas where the soil is less erodible and highly responsive to the use of productive (and soil conservation) inputs, the effect on soil productivity may mask the effect on soil degradation and a rise in the cost of the productive input may lead to a deterioration in the long run productive potential of the land. On rich soils with heavy nutrient pools, the productivity impact of soil erosion could be invisible for a long time until a significant part of the productive soil has been washed off, and high yields may still make the use of productive inputs profitable to the peasant or yields may not even decline when high costs forbid the use of productive inputs. Hence, land users lack sufficient incentives to invest on land conservation. In such a case, a tax on product price seems to be an appropriate incentive to induce peasant households to be cognizant of the effect of their production activities and the cost of soil degradation in making production decisions.

ii) Conservation is productive:

When conservation is productive, equation (44) will not have a definite sign. When $pf_{qz}z_{e_1} > pf_{qu}u_{e_1}$ in absolute terms, (44) will be negative and the two isoclines will shift down in the same direction and the result will be the same as that for unproductive conservation. But when $pf_{qz}z_{e_1} < pf_{qu}u_{e_1}$ in absolute terms, (44) will be positive and the two isoclines will shift in opposite directions. In the latter case, an increase in the price of the yield-increasing input will unambiguously increase the steady state soil fertility level. The effect on the shadow value of the soil will, however, depend on the size of the relative shift in the two isoclines. When the positive effect in reducing soil degradation exceeds the negative effect on soil productivity, the shadow value of the soil will decrease and conversely.

5.2.2.5 The effect of intensification without technological change

Family labor is the major variable factor available to peasant households for allocation in production and soil conservation activities on the farm and generation of supplementary income from off-farm income-earning opportunities. Hence, it is possible to perceive the control variables in the model z and u as the respective shares of the total labor use in cultivation and land conservation activities. Therefore, as Barbier (1990) suggests, it is also possible to analyze the long-term effects on the soil of the change in the intensity of labor use in cultivation and conservation activities. An increase in the intensity of labor use in cultivation per unit of agricultural land, in the context of peasant agriculture, may result from several factors, like an increase in population pressure, an increase in family size, a decline in the productivity of agricultural land, or lack of other income-earning opportunities the cumulative effects of which may severely limit the availability of cultivable land. An increase in population pressure and lack of off-farm employment opportunities increase the man-to-land ratio. As a result, the smallholder, short of other yield-increasing inputs may choose to intensify cultivation (eg. shortening fallow periods and increasing the frequency plowing before planting). The effect of this type of "autonomous intensification" without the associated increase in the use of soil-replenishing inputs (eg. fertilizer) could be seen from

$$\left.\frac{\partial\lambda}{\partial z}\right|_{\dot{\lambda}=0} = \frac{pf_{qz}}{\psi_{\lambda}} > 0 \qquad (46)$$

$$\left.\frac{\partial\lambda}{\partial z}\right|_{\dot{q}=0} = \frac{-h_z}{\phi_{\lambda}} > 0 \qquad (47)$$

Hence, as (46) and (47) suggest, an increase in the share of labor use in cultivation will shift both the $\dot{\lambda}=0$ and $\dot{q}=0$ isoclines upwards regardless of the effect of conservation in production. The value of the soil will increase in the long run due to an increased stress from the increased intensity of labor use per unit of cultivated land. The effect on the steady state soil fertility level will, however, depend on the relative strength of the negative effect on the soil of the increasing intensity of labor use and the impact on productivity. When the effect on soil degradation is more stronger than the resulting improvement in soil productivity $((-h_z)/\phi_{\lambda}>(pf_{qz})/\psi_{\lambda})$, an increase in the intensity of labor use in cultivation will lower the long-term productivity of agricultural land. In the case where the effect of the soil productivity improvement overwhelms the associated effect on soil degradation $((pf_{qz})/\psi_{\lambda}>(-h_z)/\phi_{\lambda})$, an increase in the intensity of labor use in cultivation may lead to an improvement in the long-term soil fertility index. In highly degraded areas with unproductive soils, the condition which tends to lower the long run productive potential of the land is strong.

This suggests that conditions which decrease the intensity of labor use in cultivation or increase the land-to-man ratio, such as access for off-farm employment and possibilities for outmigration or reduction of family size through family planning services, will be beneficial for regulating the problem of soil degradation in the long run. The reduced pressure on the land as a result of off-farm income-earning opportunities and diminished dependence on the land could, however, have mixed effects on soil conservation. Whilst the reduced subsistence demand on land tends to improve the long-term soil fertility level, a reduction in on-farm labor supply may decrease the labor time available for soil conservation or increased income-earning opportunities in activities other than farming may reduce the incentive for sustainable management of the soil stock.

5.2.2.6 The effect of a change in conservation effort

i) Conservation is counterproductive:

The effect of increased effort spent on land conservation is more straightforward and could be captured from

$$\left.\frac{\partial\lambda}{\partial u}\right|_{\dot{\lambda}=0} = \frac{pf_{qu}}{\psi_{\lambda}} < 0 \qquad (48)$$

$$\left.\frac{\partial\lambda}{\partial u}\right|_{\dot{q}=0} = \frac{-h_u}{\phi_{\lambda}} < 0 \qquad (48')$$

The two isoclines will shift downwards in the λq plane. Due to increased conservation effort, the marginal user cost of soil will decrease unequivocally. The effect on the steady state soil fertility level will, however, depend on the relative strength of the positive effect in reducing soil erosion and the negative effect on soil productivity. When the effect on curbing soil erosion dominates the negative effect on soil productivity, the steady state soil fertility will improve and conversely.

ii) Conservation is productive:

In this case, the two isoclines shift in opposite directions in the λq plane (ie. the $\dot{\lambda}=0$ isocline shifts up while the $\dot{q}=0$ isocline shifts down) since (48) is positive. Thus, when conservation is productive, the effect of increasing the labor time available for soil conservation is unambiguous increase in the long-term productive capacity of the soil. Farming systems with a reduced labor requirement in cultivation which allow the use of increasing share of labor in land conservation activities may thus have a higher chance of success in conserving the productive potential of the soil. As mentioned above, conditions which may reduce the intensity of labor use in conservation, like outmigration and off-farm income- earning opportunities would, according to (48) and (48'), tend to decrease the long-term quality of the soil. However, migration has a beneficial effect of regulating population pressure, while higher income earned from off-farm sources, apart from serving as a means of livelihood security which could buffer the variation in farm income, provides a vital source of scarce capital to the household which could be used to make farm-level investments for controlling soil erosion. Hence, the effect of migration and off-farm income is more complex than suggested by conditions (46) to (48) and thus needs to be determined empirically in the light of specific circumstances in every location.

6. Regulation of the soil erosion externality

Under the conditions of smallholder farming based on highly erodible and low quality upland soils, the analytical comparative static results presented from the intertemporal soil use model suggest that either a subsidy on the use of a soil-conserving input or a tax on the use of a soil-degrading productive input are required to induce the land user to take necessary actions for maintenance of the productive potential of agricultural land. Even if the land user may voluntarily adopt conservation practices on profitability grounds, the existence of external damage costs may imply that the level of conservation achieved could be insufficient to internalize the external costs of erosive activities. However, one major difficulty is that even if a tax or a subsidy is signified, we do not yet know the exact level of the subsidy or the tax required to regulate the soil erosion externality in the current period.

Besides, the soil conservation related literature also points to various reasons why rural households may not even adopt profitable land conservation measures to control damages from land degradation in the long run (eg. see Ervin, 1982; Ervin and Ervin, 1982; Fujisaka, 1994; Lutz *et al.*, 1994). Some of the frequently mentioned factors include a high rate of time preference and risk aversion among poor farmers, asymmetric information about the benefits of soil conservation, missing or imperfect factor markets and capital constraints, and insecurity of tenure.

Despite the lack of widespread voluntary adoption of land conservation practices which enhance the sustainability of smallholder farming, a mandatory approach towards regulating soil loss has not yet been practiced in many developing countries. A major difficulty for enforcing a mandatory soil conservation program has been the difficulty of applying the standard first-best pollution control policies in which a generator of an externality is confronted with a (dis)incentive (eg. tax or subsidy) equal to the marginal external cost on society per unit of pollution generated or abated. This is particularly considered a major problem for non-point source pollution in which (a) only the joint production of the pollutant is observable while individual levels of emissions are dispersed and costly to monitor, and (b) the relations between emissions and ambient environmental quality are stochastic (e.g. see Segerson, 1988).

However, a tax on inputs could be replaced for a tax on pollutants (in this case soil loss) when individual source sediment loss cannot be monitored (Holtermann, 1976; Griffin and Bromely, 1982). As long as the soil erosion or sediment production function could be established as a function of the level of input use, a per unit tax on soil-degrading productive inputs and a per unit subsidy on soil-conserving inputs could be used to regulate the soil erosion externality. Alternatively, a tax on soil loss predicted from the level of input use could also be used.

In what follows, a simplified analytical model will be developed to illustrate the exact level of taxes and subsidies (a tax on predicted soil loss or soil-degrading inputs or a subsidy on soil-conserving inputs) required as policy instruments (at least in principle) to regulate a typical soil erosion externality in peasant agriculture.

For notational convenience and without loss of generality, assume that a group of peasant farmers own and cultivate single plots in such a way that erosion originating from the field of one farmer imposes an externality both on-site and off-site on the fields of other farmers. Hence, in the sense of Baumol and Oates (1988), the erosion externality is depletable (damages to one farm diminish the level of erosion available to cause damages to other farms) and imperfectly mixed. The agricultural output and externality (in this case soil loss) production function are respectively,[21]

$$\begin{gathered} Y_k = f^k(z_k, u_k, s_k) \\ f_z^k > 0,\ f_u^k > 0,\ f_s^k < 0 \quad for \quad all \quad k \end{gathered} \tag{49}$$

$$\bar{s}_k = g^k(z_k, u_k, x_k)$$
$$g_z^k > 0,\ g_u^k < 0,\ g_x^k \gtreqless 0 \quad \textit{for all } k \tag{50}$$

$$s_k = \sum_{j=1}^{n} \gamma_{kj} \bar{s}_j \quad j=k \text{ for soil loss from } k\text{'s own field} \tag{51}$$

Where,

Y_k = output of household *k*

z_k, u_k = the productive and soil-conserving inputs used by household *k*

x_k = a vector of land characteristics which influence erosion production on the field of household *k*

$\bar{s}_k$ = the soil erosion externality from the field of household *k*

s_k = the soil erosion externality suffered by household *k*

γ_{kj} = the dispersion coefficient of the soil erosion externality

k, j = *1,..., n* farm households.

The specification of the agricultural output (49) and the soil loss (50) production functions as joint products of the same set of inputs is similar to that given in (1) and (2). The *f* and *g* functions are assumed to be well-behaved and twice continuously differentiable. From (49) the marginal product of the externality is negative since removal of soil nutrients will visibly or invisibly reduce crop yield. From (50), abatement inputs reduce soil loss, while traditional production inputs increase it, hence the partial derivatives with respect to these inputs are negative and positive accordingly.

One approach to derive the socially optimal level of output, input use and abatement is the one which maximizes a randomly selected farmer's output (farmer one in this case) subject to the constraint that the output of every other farmer is non-declining (52), the total use of the two inputs equals the initial endowment (53), and the above constraints (49) to (51).

$$Y_k \geq Y_k^* \quad \text{for } k = 2, \ldots, n \tag{52}$$

$$\sum_{k=1}^{n} z_k = V; \ \sum_{k=1}^{n} u_k = T \tag{53}$$

The Lagrangian of this maximization problem becomes:[22]

$$\begin{aligned} \max \ L = & \sum_{k=1}^{n} \alpha_k (Y_k - Y_k^*) + \sum_{k=1}^{n} \lambda_k \left(f^k(z_k, u_k, s_k) - Y_k \right) + \sum_{k=1}^{n} \eta_k \left(g^k(z_k, u_k, x) - \bar{s}_k \right) \\ & + \omega_z \left(V - \sum_{k=1}^{n} z_k \right) + \omega_u \left(T - \sum_{k=1}^{n} u_k \right) + \sum_{j=1}^{n} \mu_j \left(\sum_{j}^{n} \gamma_{kj} \bar{s}_j - s_k \right) \end{aligned} \tag{54}$$

The Lagrangian multipliers $(\alpha_k, \lambda_k, \eta_k, \omega_i, \mu_j$ for $i = z, u)$ are respectively the shadow value of an incremental unit of farmer k's output, the marginal cost of an additional unit of output, the cost of a unit of soil erosion from the field of household k, the value of a unit of the *ith* input and the shadow value of a unit of the cumulative externality produced (suffered) by household k.

Equation (54) yields the following first order conditions:

$$L_{Y_k} = \alpha_k - \lambda_k = 0 \quad \text{for all } k \tag{55}$$

$$L_{ik} = \lambda_k f_i^k + \eta_k g_i^k - \omega_i = 0 \quad for \ all \ i, \ k \ (i = z, u) \tag{56}$$

$$L_{s_j} = \lambda_j f_s^j - \mu_j = 0 \quad \text{for all } j \tag{57}$$

$$L_{\bar{s}_k} = -\eta_k + \sum\nolimits_j \mu_j \gamma_{kj} = 0 \quad \text{for all } k \tag{58}$$

Substituting (57) into (58) yields the following result which captures the effect of the soil erosion externality.

$$\eta_k = \sum_{j=1}^{n} \gamma_{kj} \lambda_j f_s^j \tag{59}$$

From equation (59), the marginal social cost of the externality generated by household k is the sum of the value of forgone output by all affected farms as the externality disperses across the fields including the damage inflicted on one's own farm. In the context of the previous dynamic analysis, η_k is the social marginal user cost of soil erosion. Theoretically, in the first best case, the disincentive to regulate the soil loss externality should equal the marginal social cost of the externality as given by (59). This will induce household k to account for the external social cost of erosion originating from its field. Using equation (59) in (56) yields the following result.

$$\lambda_k f_i^k + \sum_{j=1}^{n} \gamma_{kj} \lambda_j f_s^j g_i^k = \omega_i \quad \text{for } i = z,\ u \tag{60}$$

From equation (60), the socially optimal level of use of each input requires equating its marginal value product to its marginal social cost. The exact dynamic analogue of (60) is given by the maximum principle conditions of (7) and (8). The optimal incentive for the use of the inputs in each period in a dynamic context will be given by - $D_i + \lambda h_i$ (for $i = z, u$). The dynamic incentive instrument in each period will thus be equal to the negative of the second term in the left hand side of (60). In line with (60), optimal input use calls for a subsidy for the soil-conserving input and a tax for the soil-degrading input.

In order to derive the optimal level of (dis)incentive to each peasant farmer, one has to look at the decentralized net income maximization problem. Following the above notation, the associated Lagrangian for an individual smallholder would be

$$\begin{aligned} \max\ \Phi &= p\ y_k - (e_z + t_z) z_k - (e_u + t_u) u_k \\ &+ \beta_k \left(f^k(z_k,\ u_k,\ s_k) - y_k \right) + \theta_k \left(g^k(z_k,\ u_k,\ x_k) - \bar{s}_k \right) \end{aligned} \tag{61}$$

The Lagrangian multipliers $(\beta_k,\ \theta_k)$ are the marginal cost of output and the marginal cost of soil loss to farmer k, respectively. The output price is given by p. The unit cost of input i ($i = z, u$) is given by e_i, and t_i is the per unit tax/subsidy on input i. The first order conditions to (61) are

$$\Phi_{y_k} = p - \beta_k = 0 \tag{62}$$

$$\Phi_{ik} = -(e_i + t_i) + \beta_k f_i^k + \theta_k\ g_i^k = 0 \quad \text{for } i = z,\ u \tag{63}$$

$$\Phi_{\bar{s}_k} = -\theta_k = 0 \tag{64}$$

Since the total tax on emissions (soil loss) equals the total tax/subsidy on inputs with constant returns to scale in g^k, we may substitute $t\bar{s}_k$ for $t_z z_k + t_u u_k$ in (61) and derive [23]

$$\beta_k f_i^k - t^k g_i^k = e_i \quad \text{for all k, i} = z,\ u \tag{65}$$

Comparing result (60) with (65) and assuming the input price (e_i) equals the shadow price of the input (ω_i) and $\beta_k = \lambda_k$ (for all k), the optimal tax on soil loss will be given by

$$t^k = -\sum_{j=1}^{n} \gamma_{kj} \lambda_j f_s^j \tag{66}$$

Equation (66) shows that the optimal per unit tax on soil loss is positive as long as f_s^j is negative and it varies across peasant households since the social damage resulting from the soil erosion externality varies according to the dispersion coefficient. Since optimality requires that every generator of externality should be confronted with a disincentive equal to the marginal external cost (Baumol and Oates, 1988), each household will have to pay a tax on soil loss equal to the marginal external damages inflicted on all affected farms.

Substituting (64) into (63) and comparing it to (65) and (60), the optimal level of tax on inputs ($i = z, u$) is also given by

$$t_i^k = t^k g_i^k = -\sum_{j=1}^{n} \gamma_{kj} \lambda_j f_s^j g_i^k \tag{67}$$

In general, a tax on inputs will be positive if g^k_i is positive. However, (67) shows that society must subsidize the rural land user for soil-conserving inputs when g^k_i is negative. The level of the incentive is also likely to vary across households due to variations in γ_{kj} and g^k_i. The level of taxes/subsidies derived here are socially optimal only when regulation is costless. In the real world, as it is true with regulation of any externality, regulation brings with it enforcement costs. Incomplete information may also prevent assessment of the exact incentive level to every "polluter". Because of this, taxes/subsidies may at best be used to approximate the exact incentive level which internalizes the externality to maximize social efficiency.

In the context of peasant farming, the problem becomes much more complicated due to high cots of intervention resulting from high transaction costs and imperfect information. Large number of "polluters", fragmentation of holdings, and the difficulty of estimating the dispersion matrix which may also exhibit seasonal variation make a regulatory approach a difficult policy choice. Although the erosion function may be estimated from the level of inputs in production and conservation (eg. the level of labor use in production and conservation) for each category of agricultural land (eg. soil type, slope, etc.) and crop type, lack of empirical data on these variables makes the use of a regulatory approach largely inapplicable to smallholder farming at present.

Besides, when the predominant factor input is labor and other yield-increasing inputs are rarely used, a tax on labor use in production may lead to a reduction in output and income in the short-run, particularly when the soil is not very responsive to increasing conservation effort. When conservation does not provide immediate benefits to the smallholder, diversion of labour use into conservation implies a trade-off between production and conservation and the only way to abate soil loss with traditional technologies of low productivity may presuppose a reduction in output. When a reduction in food production is the only means of abatement, a tax on inputs or soil loss could lead to below subsistence levels of food production. This could particularly be the case since the subsidy on the ameliorative input is often not directly paid to the household but used to pay for hired labor in conservation activities (eg. food-for-work programs) on the peasant's farm.

Therefore, in the second-best case, under peasant farming, enforcing a "polluter pays principle" is difficult. A logical way of conserving the soil without severely affecting the welfare of the poor, as (67) suggests, is through subsidization of abatement inputs. As it has been argued in relation to (42) and (43) and correctly noted by Lutz *et al.*, (1994), subsidies are not required in areas where rural land users have sufficient economic incentives to control the long-term productivity damage from soil erosion. When the problem is not lack of economic incentives, but related to other constraints, like provision of credit services or security of tenure, subsidies on conservation inputs will not improve economic efficiency. Lutz *et al.*, (1994) also point to several problems of targeting subsidies and designing appropriate incentive structures to rural land users. The subsidy for soil conservation, however, could be targeted in various ways. One approach could be linking a credit subsidy for the use of a productive input (eg. fertilizer) with a requirement to install appropriate conservation practices (Holden and Shanmugaratnam, 1995). Such a policy which requires cross-compliance from the part of the peasant farmer may be very effective especially when the productive and soil conservation inputs are complementary.

7. Summary and Conclusions

Land degradation is perceived as one of the most important environmental problems in the developing countries. In smallholder farming, soil erosion by water is the predominant form of land degradation. But, the problem of soil erosion is often presented in physical terms (as in tons of productive soil lost per hectare per year) and the causes usually blamed for excessive erosion are overcultivation, overgrazing, overpopulation, deforestation, etc. An economic and institutional analysis of the soil degradation problem presented here, however, goes further to reveal the subtle and obscured underlying causes behind any departure between the socially and privately optimal rates of soil conservation. The results suggest that when the input and output markets are perfect and where external costs of soil erosion do not exist, the level of abatement achieved by private decisions of smallholders will closely mimic the socially optimal path for soil use. Under the circumstances of smallholder farming, where none of these conditions may hold, the private user cost of soil erosion and hence the smallholder's intertemporal plan for soil use is likely to deviate from that which maximizes social welfare even in the absence of external costs of soil erosion. The interlinked effects of poverty, environmental degradation and population growth, coupled with factor market imperfections (particularly missing credit and insurance markets) and insecurity of tenure, could lead to the divergence between the private and social user costs of soil erosion and respective optimal paths of soil use.

The effects of changes in input and output prices, the discount rate, the quality of the soil, the intensity of cultivation and conservation on the short and long run soil fertility index have also been investigated. The results suggest that, in the short run, when the conservation input adds to the productivity of the soil, the effect of changes in output price, the level of soil fertility, and the cost of soil erosion on the choice and level of use of the soil-degrading input and the soil-conserving input will depend on the gain in productivity and the effect on soil degradation. When the effect on production dominates the effect on soil erosion, the use of both inputs increases with a rise in output price and an increase in soil quality. When the effect on soil erosion is more conspicuous, an increase in the marginal user cost of soil will favour the use of the soil-conserving input, but discourages the use of the soil-degrading input. A rise in the cost of an input will, however, unambiguously discourage the use of that input regardless of the effect of conservation on production.

When the conservation input package is either neutral or has a negative impact on the productivity of soil and the yield-increasing input, a rise in the price of output, an improvement in the fertility of the soil, and an increase in the cost of the soil-conserving input, encourage more intensive use of the productive input over that of the soil-conserving input. A rise in the marginal user cost of soil and an increase in the cost of the productive input, however, tend to induce improved land management at the farm level.

In the long run, in farming systems that are based on highly erodible soils where returns to the use of inputs is low and the negative impacts on soil erosion may dominate the positive effect on enhancing soil productivity, an increase in output price, a rise in the cost of conservation, an increase in the discount rate or a subsidy on the use of the soil-degrading productive input tend to lower the steady state productive capacity of the soil. Hence, under plausible assumptions, a per unit subsidy on the use of the soil-conserving input or a tax on the use of the soil-degrading input or any policy which tends to lower the real discount rate will have an unambiguous effect of increasing the long-run productivity of the soil.

Even if taxes on predicted levels of soil loss or input tax/subsidies could theoretically be used for regulation of the soil erosion externality, implementation of a mandatory soil conservation policy in the context of peasant farming is beset with several difficulties, such as lack of information and high enforcement and transaction costs. However, adoption of soil conservation technologies will be in the best interest of the smallholder only when the net present value of incremental returns from switching are positive. In the absence of immediate economic gains, the peasant household subject to a regulatory policy, may face difficult tradeoffs between the demand for conservation and the need to meet livelihood requirements. Hence, with all limitations of pursuing a strict regulatory approach in the short run, a subsidy on the soil conservation effort or a poverty alleviation policy which would lower the land user's rate of time preference is highly desirable.

End Notes

1. The term land degradation has been defined in various ways in relation to soil erosion and desertification to describe a negative change in land productivity. The one used here addresses various processes leading to a negative change in productivity of land as that given by Dudal (1981) who defines it as '*a loss of land productivity, quantitatively or qualitatively, through various processes such as erosion, wind blowing, salinization, water logging, depletion of nutrients, deterioration of soil structure, and pollution*'.

2. Even if soil fertility and soil productivity may have different interpretations in the strict sense of the terms, in this paper, they will be generally used interchangeably. Similarly, soil degradation and land degradation are used synonymously.

3. Even if the past approach has been to use soil depth as a proxy for the inherent quality of the soil, in this paper, the soil fertility index in each period of time is assumed to depend on the depth as well as the stock of physical and chemical characteristics of the soil. For example, Pieri (1993) summarizes the attributes of the soil that control its fertility status as (a) nutrient reserve and availability, (b) physical characteristics of the soil such as structure, porosity and compaction that regulate the access of plant roots to water, air and nutrients, and (c) the system of physico-chemical regulation (eg. acidity-alkalinity and redox potential) and the system of biological regulation at rhizosphere and soil organic matter level that facilitate the synchronization of moisture and nutrients released from the soil to the plant.

4. The time subscripts of the variables and equations will be suppressed once the dynamic formulation has been introduced in the equations.

5. In this model, in order to focus on the economic effects and incentives to the smallholder arising from changes in market forces in relation to the management of land resources, technology has been kept constant. While this assumption excludes technological optimism from providing a solution to the long run environmental problems of smallholder farming, it is obvious that a technical change that increases the effectiveness and productivity of the soil ameliorative inputs or increase the productivity of the soil would have a positive impact on the long term productive quality of the soil (McConnell, 1983)

6. Although conservation will in general be considered as beneficial to crop output, some economic interpretations of the maximum principle conditions and other related issues will be given for the cases in which conservation may reduce current productivity.

7. The optimal path for $(z, u, q, \lambda, \theta)$ should also satisfy the infinite horizon transversality condition $\lim_{t\to\infty} \mathfrak{L}(t)\, e^{-\rho t}=0$. Since the t argument does not explicitly enter the objective functional and the current value Lagrangian $\mathfrak{L}$ is free of the t argument and hence its value evaluated along the optimal paths of all variables must be constant over time, the transversality condition implies that $\mathfrak{L}_t=0$ for all t. Moreover, to the extent that the objective functional contains a discount factor and the terminal state is free, the optimal trajectory of $(z, u, q, \lambda, \theta)$ should also satisfy another transversality condition $\lim_{t\to\infty} \lambda(t)\, e^{-\rho t}=0$ (Chiang, 1992).

8. In maximization of the current value Hamiltonian with respect to the control variables z and u subject to the inequality constraint (5), the invoked Kuhn-Tucker conditions (7) to (9) will be necessary only when a constraint qualification is satisfied (Kamien and Scwartz,1971; Chiang, 1992). Since the constraint function (5) is linear in z and u (contains no z or u), the constraint qualification is fulfilled.

9. Sediment accumulation on other fields is often considered as a diseconomy since continued erosion over some time may lead to accumulation of infertile sediment which may decrease the productivity of the recipient soil. On valley bottoms which serve as a sink for fertile soil washed off erodible slopes, the externality could be positive at least for a limited period of time. However, externalities, whether adverse or beneficial, cause market outcomes to be inefficient since they lead to misallocation of resources from society's point of view. Aggregate estimates on soil erosion could also be exaggerated when moved soil which may have been deposited on other agricultural land is considered as lost soil. However, excessive movement of soil into low-lying areas, even if productive, may diminish the area of cultivable land through degradation, and soil deposited on fields of a different owner is lost to the land owner upstream.

10. As Nowak (1988) notes, the paradigm shift in the conservation arena implies that the land users are not the primary beneficiaries of soil and water conservation as the major intent is to increase the welfare of non-farmers. This presupposes that conservation is more beneficial to society than the individual user which in turn implies that voluntary conservation behavior may not be in the best interest of the private user and hence the soil erosion externality should be subject to a regulatory approach to conservation.

11. In reality $k = pf_q(q(t),z(t), u(t)) + \theta$ is constant when $dk/dt = f_{qq}\,(\partial q/\partial t)+f_{qz}\,(\partial z/\partial t) + f_{qu}\,(\partial u/\partial t) + (\partial\theta/\partial t) = 0$. This may hold on a linear segment of the yield-soil quality curve where f_q is constant and the sustainability constraint is constant or in the steady state. In the latter case, $\partial\lambda/\partial t=0$ and $\lambda(t)$ will be given by (1.2). This simplifying assumption may be used to show the relationship of $\lambda(t)$ to the discount rate (r). When k is not a constant, $\lambda(t)$ will have a complex term that requires specification of the functional forms to solve for its explicit path. If we assume $\rho = r$, and that the marginal value of the soil measured by prices (pf_q) and θ are constants, (10) could be rewritten as

$$\dot{\lambda} - r\lambda = -k$$

The time path of the costate variable $\lambda(t)$ can now be written as

$$\lambda(t) = Ae^{rt}+k/r \tag{1.1}$$

Since the objective functional contains a discount factor and the terminal state is free, the infinite horizon transversality condition $\lim_{t\to\infty} \lambda(t)e^{-rt}\to 0$ could be invoked to definitize the the arbitrary constant (A) in (20) (Chiang, 1992). Since the second term in the right hand side of (20) will vanish as $t\to\infty$, the arbitrary constant should be zero to satisfy the transversality condition. This implies that the costate trajectory will be given by

$$\lambda(t) = k/r = \frac{[pf_q + \theta]}{r} \tag{1.2}$$

12. The choice of the discount rate is one of the long-debated and unresolved issues in the economics profession (eg. see Young, 1992; Howarth and Norgaard, 1993; Pearce et al, 1990 and the vast references there in). The process of discounting is in effect equivalent to assigning temporal weights

that decline with an increment of time in assessing the present value of benefits and costs as they accrue over time. While many have noted the apparent ethical paradox of discounting and dismiss the whole rationale for using a positive discount rate, there also exist some who argue that the social discount rate should be less than the private or market determined rate of discount. In the context of smallholder farming, the latter suggests that the private rate, even if it reflects the market rate of discount, could still be higher than the level society should be willing to weigh future benefits and costs. Other than pointing to some of the existing debate and arguments for the possible divergence between the *private* (the market-determined rate of discount) and *social* rate of discount, space limits further treatment of the vast literature that followed the extended debate on the discounting issue.

13. Whilst the Dillon and Scandizo interview technique for eliciting certainty equivalents of risky prospects may be subject to interviewer bias, the results of other studies based on one period gambling experiments, often without the probability of loss, may provide erroneous inferences about the risk behavior of farmers in their real business of survival.

14. Usurious rates of interest in the informal markets of some rural areas could be illusory since the effective rate, accounting for the risk of default (Basu, 1984) and large transactions costs, could be the same as the rate in the formal credit market.

15. In order to focus on the conditions for which the derivative obtains a definite sign and the use of the input is either encouraged or discouraged with respect to a change in a parameter value, the possibility that the comparative static derivative could be zero will be masked.

16. Barbier (1990) uses a conservation-neutral production function and obtains the same results given here when conservation is assumed to be counterproductive.

17. Some phase trajectories cross one of the isoclines and the slope of the trajectories on such stationary points will be zero and infinite when they cross the $\dot{\lambda}=0$ and $\dot{q}=0$ isoclines,respectively. Hence, these points are indicated by horizontal and vertical sketching bars in the phase diagram.

18. The optimal state trajectory is the one which satisfies the infinite horizon transversality condition and the one which lies on the stable branch. To choose a stable branch from a family of phase trajectories is equivalent to choosing a particular solution from a family of general solutions by definitizing an arbitrary constant with the help of appropriate transversality conditions (Chiang, 1992).

19. The effect of the price change on the steady state user cost of the soil is directly given by (39) and (40). The effect on the steady state soil fertility index, however, is captured by the magnitude of the relative shift in the two isoclines. In addition, note that inequalities given in parenthesis when the numerators are negative refer to numerical (absolute) values rather than algebraic values. The interpretation of the effect on the soil fertility index and the marginal user cost of soil will be especially easier when $\phi_{\lambda}=\psi_{\lambda}$.

20. The resulting analytical effects could easily be shown by redrawing the isoclines of the phase diagram given in Figure 2. Since the phase diagram depiction for the relative shifts in the isoclines is straightforward, in the pursuing analysis, only intuitive explanations will be given without sketching the phase diagram for each case.

21. Following the earlier notation, the subscripts of a function with respect to the decision variables (y, z, u, s) represent derivatives. For example, for household k the marginal product of the productive input $\partial f^k/\partial z_k$ will be given as f^k_z. The k or j subscripts on the choice variables or the Langrangian

multipliers in this section stand for specification of household *k* or *j* and should not be confused for the derivatives.

22. The social maximization problem in (54) maximizes the output of farmer 1 (Y_1) while the output of all other farmers is non-decreasing or remains unaffected (i.e., $Y_k \geq Y^*_k$ for $k > 1$). This approach is consistent with the Pareto principle for socially efficient production (Stevens, 1988). It does not require that consumption of each household should remain fixed. This general formulation suggested by Baumol and Oates (1988, pp.38) assumes that $\alpha_1 = 1$, and $Y^*_1 = 0$. An alternative formulation would be

$$\max\ L = Y_1 + \sum_{k=2}^{n} \alpha_k (Y_k - Y_k^*) + \sum_{k=1}^{n} \lambda_k \left(f^k(z_k, u_k, s_k) - Y_k \right) + \ldots + \sum_{j=1}^{n} \mu_j \left(\sum_{j}^{n} \gamma_{kj} \bar{s}_j - s_k \right) .$$

The Kuhn-Tucker condition for $Y_k \geq Y^*_k$ is masked in the FOCs.

23. Using a similar model, Stevens (1988) asserts that effluent charges and input taxes/subsidies could have differing fiscal implications depending on the returns to scale in residual production function. When the technology exhibits constant returns to scale, the total effluent charge payments are equal to the total input tax/subsidy payments. When there are increasing or decreasing returns to scale in externality generation, the total input tax/subsidy payments will be larger or smaller than the total effluent charges, respectively. Both policy instruments also reduce post-regulation farm income since land users can not receive a net total subsidy when the input tax/subsidy approach is used.

Appendix I

Totally differentiating the maximum principle conditions (14) and (15)

$$
\begin{aligned}
dH_z &= d\,[pf_z - e_1 + \lambda h_z] = 0\\
dH_u &= d\,[pf_u - e_2 + \lambda h_u] = 0
\end{aligned}
$$

Using dH_z first

$$
\begin{aligned}
dH_z &= pdf_z + f_z\,dp - de_1 + \lambda dh_z + h_z d\lambda = 0\\
&= p(f_{zz}dz + f_{zu}du + f_{zq}dq) + f_z dp - de_1 + \lambda(h_{zz}dz+h_{zu}du) + h_z d\lambda = 0
\end{aligned}
$$

which implies

(a) $(pf_{zz} + \lambda h_{zz})dz + (pf_{zu} + \lambda h_{zu})du = de_1 - pf_{zq}dq - f_z dp - h_z d\lambda$

Similarly using dH_u we could derive

$$
\begin{aligned}
dH_u &= pdf_u + f_u dp - de_2 + \lambda dh_u + h_u d\lambda = 0\\
&= p(f_{uu}\,du + f_{uz}dz + f_{uq}dq) + f_u\,dp - de_2 + \lambda(h_{uu}du+h_{uz}dz) + h_u d\lambda = 0
\end{aligned}
$$

which again implies

(b) $(pf_{uz} + \lambda h_{uz})dz + (pf_{uu} + \lambda h_{uu})\,du = de_2 - pf_{uq}dq - f_u dp - h_u d\lambda$

A simple transformation of (a) and (b) into a matrix format will provide (22).

$$
\begin{bmatrix} pf_{zz}+\lambda h_{zz} & pf_{zu}+\lambda h_{zu}\\ pf_{uz}+\lambda h_{uz} & pf_{uu}+\lambda h_{uu} \end{bmatrix}
\begin{bmatrix} dz\\ du \end{bmatrix}
=
\begin{bmatrix} -pf_{zq}dq - f_z dp + de_1 - h_z d\lambda\\ -pf_{uq}dq - f_u dp + de_2 - h_u d\lambda \end{bmatrix}
$$

Appendix II

(a) $$\frac{\partial z}{\partial p} = \frac{-f_z(H_{uu}) + f_u(H_{zu})}{|J|} > 0$$

(b) $$\frac{\partial u}{\partial p} = \frac{-f_u(H_{zz}) + f_z(H_{uz})}{|J|} < 0$$

(c) $$\frac{\partial z}{\partial q} = \frac{-pf_{zq}(H_{uu}) + pf_{uq}(H_{zu})}{|J|} > 0$$

(d) $$\frac{\partial u}{\partial q} = \frac{-pf_{uq}(H_{zz}) + pf_{zq}(H_{uz})}{|J|} < 0$$

(e) $$\frac{\partial z}{\partial \lambda} = \frac{-h_z(H_{uu}) + h_u(H_{zu})}{|J|} < 0$$

(f) $$\frac{\partial u}{\partial \lambda} = \frac{-h_u(H_{zz}) + h_z(H_{uz})}{|J|} > 0$$

(g) $$\frac{\partial z}{\partial e_1} = \frac{H_{uu}}{|J|} < 0$$

(h) $$\frac{\partial u}{\partial e_1} = \frac{-H_{uz}}{|J|} > 0$$

(i) $$\frac{\partial u}{\partial e_2} = \frac{H_{zz}}{|J|} < 0$$

(j) $$\frac{\partial z}{\partial e_2} = \frac{-H_{zu}}{|J|} > 0$$

Appendix III

From the maximum principle conditions given in (16) and (17), we could define $\dot{\lambda}$, and $\dot{q}$ as a function of the variables λ and q as in (33) and (34) and form the Jacobian matrix which should be evaluated at the steady state point E. The Jacobian matrix will be of the form

$$J_E = \begin{bmatrix} \psi_\lambda & \psi_q \\ \phi_\lambda & \phi_q \end{bmatrix}$$

A characteristic root test for a saddle point equilibrium then requires that $|J_E| = r_1 r_2 < 0$ (Chiang, 1992). The elements of $\mathbf{J_E}$ are given by

$$\frac{\partial \psi}{\partial \lambda} = r - pf_{qz}z_\lambda - pf_{qu}u_\lambda > 0$$
$$\frac{\partial \psi}{\partial q} = -pf_{qz}z_q - pf_{qu}u_q - pf_{qq} > 0$$
$$\frac{\partial \phi}{\partial \lambda} = h_z z_\lambda + h_u u_\lambda > 0$$
$$\frac{\partial \phi}{\partial q} = h_z z_q + h_u u_q < 0$$

Hence, given the assumptions of the model, the $|J_E| < 0$. This implies that the two roots r_1 and r_2 have opposite signs and the intertemporal equilibrium of λ and q is characterized as locally a saddle point.

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Table 1.
Comparative statics of temporary equilibrium when conservation adds to the short-term productivity of the soil.

Effect of → on ↓	Output price (p)		Soil fertility index (q)		Marginal user cost of soil (λ)		Price of the productive input (e_1)		Price of the conservation input (e_2)	
	A	B	A	B	A	B	A	B	A	B
The use of the productive input (z)	+++	I	+++	I	I	- -	- -	- -	- -	+++
The use of the soil-conserving input (u)	+++	I	+++	I	I	+++	- -	+++	- -	- -

Note: Scenario A = Effects on production dominate effects on soil degradation ($H_{zu} > 0$).
Scenario B = Effects on soil degradation dominate effects on production ($H_{zu} < 0$)
+++ = positive effect, - - = negative effect, I = effect indeterminate.

Table 2.
Comparative statics of temporary equilibrium when conservation is unproductive in the short-term.

Effect of → on ↓	Output price (p)	Soil fertility index (q)	Marginal user cost of soil (λ)	Price of the productive input (e_1)	Price of the soil-conserving input (e_2)
The productive input (z)	+++	+++	- -	- -	+++
The soil-conserving input (u)	- -	- -	+++	+++	- -

Table 3.
Comparative statics of the steady state equilibrium when conservation is unproductive to the soil.

Effect of → on ↓	Output price (p)		Discount Rate (r)	Price of the productive input (e_1)		Price of the conservation input (e_2)		Increased intensification		Increased conservation	
	A	B		A	B	A	B	A	B	A	B
The soil fertility index (q)	++	--	--	--	++	++	--	++	--	--	++
The marginal user cost of soil (λ)	++	++	--	--	--	++	++	++	++	--	--

Note: Scenario A = Effects on production dominate effects on soil degradation.
Scenario B = Effects on soil degradation dominate effects on production.
++ = positive effect, -- = negative effect, I = effect indeterminate.

Figure 1. Optimal level of use of the soil-conserving input when it contributes to or reduces yields in the short run.

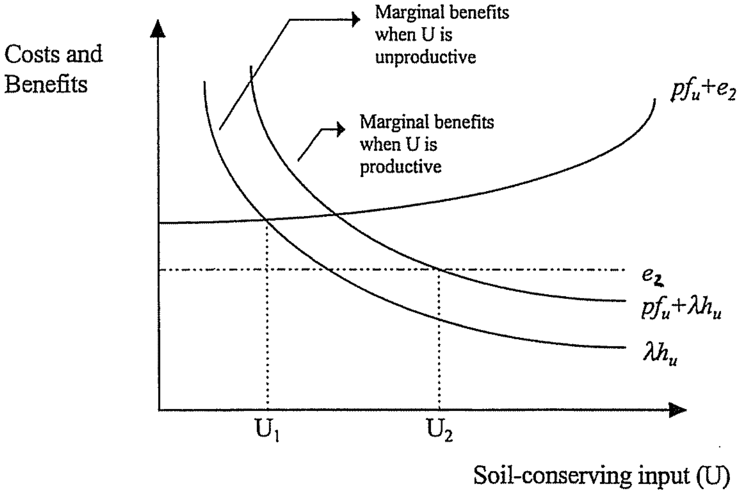
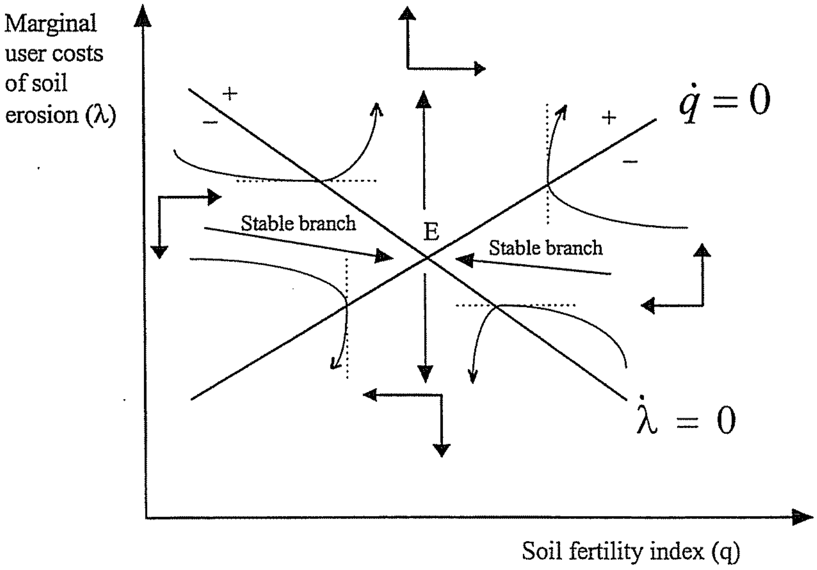


Figure 2. Phase diagram analysis of the smallholder's soil use problem.



Resource Degradation and Adoption of Land Conservation Technologies in the Ethiopian Highlands: A Case Study in Andit Tid, North Shewa

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Abstract

This paper reports results from a study of resource degradation and conservation behavior of peasant households in a degraded part of the Ethiopian highlands. Peasant households' choice of conservation technologies is modeled as a two-stage process: recognition of the erosion problem, and adoption and level of use of control practices. An ordinal logit model is used to explain parcel-level perception of the threat of the erosion problem and the extent of use of conservation practices. Results show the importance of perception of the threat of soil erosion; household, land and farm characteristics; perception of technology-specific attributes, and land quality differentials in shaping conservation decisions of peasants. Furthermore, where poverty is widespread and appropriate support policies are lacking, results indicate that population pressure per se is unable to encourage sustainable land use. The challenge of breaking the poverty-environment trap and initiating sustainable intensification thus require policy incentives and technologies that confer short-term benefits to the poor while conserving the resource base.

Key words: Land degradation, peasant agriculture, conservation technology adoption, ordinal logit models.

1. Introduction

In many agriculture-based developing countries, environmental degradation mainly takes the form of soil nutrient depletion and loss of food production potential. Reversal of the erosion-induced productivity decline and ensuring adequate food supplies to the fast growing populations in these countries posit a formidable challenge. The complex interlinkages between poverty, population growth, and environmental degradation (Dasgupta and Mäler, 1994; Reardon and Vosti, 1995) offer another dimension to the land degradation problem. In Ethiopia, in response to extensive degradation of the resource base, new land conservation technologies were introduced in some degrading and food-deficit areas of the highlands, mainly through food-for-work incentives since the early 1980s. However, sustained adoption of the new technologies has become a vital concern when peasants begun to dismantle structures once the incentives were discontinued and the coercive approach was abrogated following the change in economic policy in March 1990 and subsequent liberalization of the economy. Since then, peasants who seemed to be adopters in the presence of incentives and coercive pressure were found to behave differently, dismantling structures entirely or selectively, or retaining them in their initial state.

Several factors that condition peasants' adoption decisions have been discussed in relation to production technologies (e.g. Feder *et al.*, 1985; Kebede *et al.*, 1990; Bellon and Taylor, 1993; Adesina and Zinnah, 1993). Research into the determinants of conservation investments has, however, been limited. Poverty and market imperfections may create disincentives for conservation investment. Innovations that enhance or conserve the resource base may not also provide immediate benefits to land users. Thus, a different set of policies and targeting strategies may be required to promote such investments (Holden and Shanmugaratnam, 1995). Hence, research into farm household investment behavior is useful for technology development and design of policies and strategies that promote resource-conserving land use.

Investment in land conservation may be conditioned by a number of factors that may in turn depend on the nature of rural markets. A synthesis of the factors discussed in the conservation adoption literature (Ervin and Ervin, 1982; Norris and Batie, 1987; Nowak, 1987; Gould *et al.*, 1989; Fujisaka, 1994) is depicted in a conceptual conservation decision model in Figure 1. The decision to invest in land conservation may thus depend on perception of the erosion problem; household, technology, land and farm attributes; and exogenous conditioning factors. The effect of population pressure on resource conservation is one of the most debated issues. The opposing discourse on the issue may be denoted by the Boserupian view (Boserup, 1965), for its positive role, and the neo-Malthusian view (after Malthus, 1798), for its negative role.

The purpose of this paper is, therefore, to examine the effect of some of the factors synthesized in Figure 1 on smallholders' choice of conservation practices based on data gathered from a highly erodible area in the central highlands of Ethiopia. The rest of the paper is organized as follows. Section 2 outlines the setting and describes the study site. The analytical model of adoption behavior is developed in section 3. Section 4 deals with empirical formulation of the model and the hypothesized effects. Section 5 presents and discusses the analytical results of the study and the paper ends with some policy conclusions in section 6.

2. Resource Degradation and Past Soil Conservation in Ethiopia

The Ethiopian economy has largely remained dependent on agriculture which in any single year provides about 46% of the GDP, over 80% of the export revenue and employment for about 80% of the population. About 46% of the land mass lies in what is called the highlands (areas >1500 meters above sea level (m a.s.l.)). The highlands harbor some 88% of the country's population, over 95% of the regularly cultivated lands and about 75% of the livestock population (FAO, 1986). Most of the agricultural output originates from fragmented micro-holdings cultivated by peasant households in the highlands. Oxen serve as a primary source of traction power. The peasant production system is often diversified across crops and livestock.

The use of external yield-increasing inputs is rudimentary and agricultural production relies heavily on technologies largely unchanged for centuries. Increasing demand for manure as a source of firewood and for crop residues as a source of feed for livestock, accompanied by high population pressure and a decline in land-man ratios, have made the traditional systems of regenerating soil fertility through fallowing and use of manure and crop residues increasingly difficult (FAO, 1986; Teklu, 1990). Intensification of cropping on sloping lands without suitable amendments to replenish lost nutrients has thus led to widespread degradation of land. Available estimates on the economic impact of soil erosion indicate an annual (average of estimates for three agro-ecological zones) on-site productivity loss of 2.2% from the 1985 yield level (FAO, 1986, pp. 223).

Despite the increasing pace of degradation, and consistent with the old development thinking which downplayed the role of agriculture, prior to 1974, the issue of conserving agricultural land was largely neglected. Awareness of the land degradation problem was incited mainly by the formation of a new socio-economic order in 1974 and the devastating famine in Wello in 1973/74. Efforts to install conservation measures on erodible lands were initiated following the 1975 land reform and establishment of the Peasant Associations (PAs), which were instrumental for mobilizing labor and assignment of local responsibilities. This was further expanded with the involvement of mainly the World Food Program since the early 1980s which provided food-for-work (FFW) incentives for conservation activities. On croplands, structural measures, mainly earth and stone bunds, were built uniformly across regions with FFW incentives in food deficit areas of the highlands. Conservation activities were mainly undertaken in a campaign often without the involvement of the land user. Peasants were not allowed to remove the structures once built but maintenance was often carried out through FFW incentives. Even if considerable areas of erodible lands have been treated, maintenance of the structures has become a cause for concern to the implementing agencies (Tato, 1990). The introduction of the economic reform program in 1990 and subsequent liberalization of the economy also brought more freedom and hence conservation structures may be removed if the land user so wishes.

The data for this study comes from a study carried out in 1994 in a highly eroded zone of the highlands (Andit Tid) where new conservation technologies were introduced in the past with FFW incentives. The survey was carried out in cooperation with the Soil Conservation Research Project (SCRP) which maintains a field station at the site. Andit Tid lies some 180 kms North East of Addis Ababa in northern Shewa. It has a bimodal rainfall pattern averaging 315.4 mm in *Belg* (Jan.-May), and 1056.8 mm in *Meher* (June-Dec.) seasons, with an annual average (1986/92) of 1372.2 mm (SCRP, 1995). Its topography lies between altitudes of 3000 and 3500 m a.s.l. and is characterized by highly dissected and very steep terrain with over three quarters of the land area having a slope of more than 25% (Gebremichael, 1989), which makes it highly vulnerable to erosion.

Two types of structural measures were introduced with FFW incentives in Andit Tid; level bunds (LB) in 1980/81 out of the SCRP catchment, and Graded Fanya-juu (GFJ) in 1982 in the catchment. Half of the 80 surveyed households owned some land within the SCRP catchment while the rest have all their parcels out of the catchment. Data collected form

452 parcels include land characteristics (slope and area), the land use type, and peasants' perceptions of the erosion problem. Land users were also asked about the kind of changes they have made on each parcel where conservation structures were built in the past. The responses generally fall into three categories: complete removal (52.8%), partial removal - every other structure in a parcel removed in a fairly consistent manner - (31%), and retention of the bunds in their initial state (16.2%).

3. The Statistical Model of Adoption Behavior

Since the dependent variables of main interest, the farmers' response to introduced conservation structures, had an ordinal categorical nature, an ordinal logit model, a variant of the ordered probit (Zavoina and McElvey, 1975), was used for the analysis of the polychotomous response data, while a binary logit is used for analysis of the data where the responses were dichotomous. Considering the ordinal logit model first, let

$$Y_i^* = \beta' \mathbf{x}_i + \varepsilon_i \qquad (1)$$

Where Y_i^* is the underlying latent variable that indexes the level of use of conservation practices on a given parcel, $\mathbf{x}_i$ is a vector of explanatory variables, β is a column vector of parameters to be estimated, and ε_i is the stochastic error term. The latent variable exhibits itself in ordinal categories, which could be coded as 0, 1, 2, ..., J. Hence, we observe a response in category j when the underlying continuous response falls in the j^th interval (suppressing the observation subscripts) as:

$$\begin{array}{ll} Y = 0 & \text{if } Y^* \le \delta_0, \\ Y = 1 & \text{if } \delta_0 < Y^* \le \delta_1, \\ Y = 2 & \text{if } \delta_1 < Y^* \le \delta_2\ , \\ \vdots & \quad\vdots \\ Y = J & \text{if } \delta_{J-1} \le Y^* \end{array}$$

where δ_j $(j = 0, 1, \ldots, J-1)$ are the unobservable cutpoint (threshold) parameters that will be estimated together with other parameters in the model. When an intercept term is included in the model, δ_0 is normalized to a zero value (Greene, 1993) and hence only J-1 additional parameters are estimated with βs.

The probabilities for each of the observed ordinal responses, which in our case had only three categories (0, 1, 2) for complete removal, partial removal, and retention of conservation structure, respectively, will be given as:

$$\begin{aligned} &P(Y=0) = P(Y^* \leq 0) = P(\beta'x + \varepsilon \leq 0) = F(-\beta'x) \\ &P(Y=1) = F(\delta_1 - \beta'x) - F(-\beta'x) \qquad (2) \\ &P(Y=2) = 1 - F(\delta_1 - \beta'x) \end{aligned}$$

where F is the cumulative distribution function (CDF) for the stochastic error term ε. As is well known, the assumptions about the functional form of F will determine whether a logit (logistic CDF), probit (standard normal CDF) or other model is used. Following Occam's razor, we use the logistic specification, but the predicted probabilities are expected to be similar to that of a probit model within the broad range of the data except at the tails (e.g. see Maddala, 1983; Aldrich and Nelson, 1984).

Interpretation of the marginal effects of changes in regressors from an ordinal probit (or logit) model is considered one of the most difficult among multinomial probit (or logit) models (Green, 1993). However, parameter estimates could be easily interpretable in the form of cumulative odds ratios if a cumulative logit model is used (Agresti, 1990). The use of a cumulative logit model assumes that the marginal effect of the regressors is proportional across all categories. In order to extend the ordinal logit to a cumulative logit, let

$$F_j(x) = P(Y \leq j|x) = P(Y^* \leq \delta_j|x) = F(\delta_j - \beta'x) \quad \text{for } j = 0, 1, \ldots, J\text{-}1 \qquad (3)$$

where F is as defined above. The linear cumulative logits (Agresti, 1990) could thus be derived from (3) as:

$$\begin{aligned} L_j(x) &= \text{Logit}\left[F_j(x)\right] \\ &= \log\left[\frac{P(Y^* \leq \delta_j)}{P(Y^* > \delta_j)}\right] \\ &= \delta_j - \beta'x \quad \text{for } j = 0, 1, \ldots, J\text{-}1. \qquad (4) \end{aligned}$$

A meaningful interpretation of the parameter estimates could be given by the use of the cumulative odds ratios. This could be derived from the difference of the logits for two different values of the regressors,

$$L_j(x = x_1) - L_j(x = x_2) = \log\left[\frac{P(Y \leq j|x_1)/P(Y > j|x_1)}{P(Y \leq j|x_2)/P(Y > j|x_2)}\right] = \beta'(x_1 - x_2) \qquad (5)$$

The cumulative odds ratio as defined in (5) is proportional to the distance between the values of the regressors, with the same proportionality constant applying to each threshold point. The interpretation is that the odds of making a response $\leq j$ are $\exp[\beta'(\mathbf{x}_1 - \mathbf{x}_2)]$ times higher at $\mathbf{x} = \mathbf{x}_1$ than at $\mathbf{x} = \mathbf{x}_2$ (Agresti, 1990).

The polychotomous response data on the dependent variable was also merged into two categories of 'adopters' and 'non-adopters' whereby complete removal of the structures on a parcel was considered as a rejection of the technology and keeping or partial removal of the structures was regarded as adoption of the technologies. For this case, a simple random utility based model of adoption behavior is used. The observed adoption choice is hypothesized to depend on the farmers' comparison of perceived net returns from the traditional (t) and introduced (n) conservation technologies. Let the *i*th farmer's perception of the net benefits (including costs of switching) from adoption of the *j*th technology (U_j) be a linear function of a set of explanatory variables ($\mathbf{x}$) and the stochastic element (υ) such that

$$U_j = \mathbf{b}_j'\mathbf{x} + \upsilon_j \quad \text{for } j = \text{t, n}. \tag{6}$$

If V^* is the unobservable variable that indexes adoption, the observed response variable (V) takes a positive value when adoption occurs such that

$V = 1$ when $V^* > 0$ (or $U_n > U_t$)

$V = 0$ when $V^* < 0$ (or $U_n < U_t$).

The probability that the new conservation technology might be adopted is given by

$$\begin{aligned} P(V=1) &= P(V^* > 0) = P(U_n > U_t) \\ &= P(\mathbf{b}_n'\mathbf{x} + \upsilon_n > \mathbf{b}_t'\mathbf{x} + \upsilon_t) \\ &= P(\upsilon_t - \upsilon_n < (\mathbf{b}_n' - \mathbf{b}_t')\mathbf{x}) \\ &= F(\beta'\mathbf{x}) \end{aligned} \tag{7}$$

where $\beta = \mathbf{b}_n - \mathbf{b}_t$ is the parameter vector to be estimated and F is the cumulative distribution function for the difference of the error terms ($\upsilon_t - \upsilon_n$). If a standard normal distribution is assumed, a probit model results. Choice of a binary logit implies a logistic distribution[1]. The logit specification was chosen for its computational ease, but similar results are expected from the use a probit specification.

4. The Empirical Model and Hypothesized Effects

4.1 Choice of explanatory variables

The choice of regressors in empirical adoption studies has often lacked a firm theoretical basis. Farm households' land use and conservation decisions are likely to be influenced by a number of factors (Figure 1). The effect of these factors on conservation investment decisions is also conditioned by the nature of rural market imperfections (Pender and Kerr, 1996; Holden *et al.*, 1996). When market distortions occur, the subjective price of the good may fall within the price band, and make production and consumption decisions nonseparable (Sadoulet and de Janvry, 1995). This result implies that conservation investments, competing for resources needed for current production or consumption, will also be nonseparable from production and consumption decisions. To the extent that endowments of assets and factors differ across households, market imperfections may thus lead to differences in conservation investments. As Pender and Kerr (1996) demonstrate, when perfect markets exist for all goods and services, households' factor endowments will have no effect on production and investment decisions. However, imperfections in labor markets force households to equate labor demand with family labor supply, and thus higher labor endowments may boost conservation investments. Imperfections in credit/capital markets also imply that households with higher savings or productive assets will be able to invest more in conservation. Distortions in land markets may also lead to differential investment behavior. Thus, where market imperfections are important, the theory of investment behavior suggests inclusion of household characteristics and asset endowments in explaining adoption decisions. Moreover, land attributes that influence the profitability or riskiness of technologies are important. So are household perceptions of technology attributes. Institutional innovations that help ease liquidity constraints needed for consumption and investment, or increase the flow of information on the impacts of soil erosion and available conservation options are also useful. A summary of all the variables used in this study is presented in Table 1.

Given the conservation decision model of Figure 1, the regressors may affect the smallholder's adoption decisions and the extent of use of conservation practices both directly and recursively through soil erosion perceptions. Accordingly, our analysis attempts to capture the two-stage conservation decision process in a model of perception (in the first stage) and a model of adoption and level of use of conservation practices (in the second stage). In the perception model, we employ an ordinal logit model to examine the factors that condition the smallholder's perceptions of the soil erosion problem on a parcel. In the second stage, two variations of the empirical models were estimated using an ordinal logit maximum likelihood algorithm (SAS, 1990) for equations (1) to (5), and a binary logit maximum likelihood algorithm (SHAZAM, 1993) for equation (7). First, similar to Ervin and Ervin (1982), the soil erosion perceptions were used directly with other regressors. Second, similar to Gould *et al.* (1989), predicted values from an OLS model[2] of soil erosion perceptions are used as regressors in a recursive form. But, unlike Gould *et al.* (1989), due to multicollinearity, we excluded variables which were significant at 5% level in the ordinal logit model of soil erosion perceptions. A binary logit model was employed to examine the factors that influence the smallholders' adoption decisions. An ordinal logit model was used to investigate the factors that condition the degree to which conservation practices are used on a given parcel.

4.2 The perception model

In the perception model, based on previous empirical research and economic theory, we included household-specific variables (level of education and age of the household head), variables that condition the diffusion of information (technology awareness, and level of contact with SCRP research and outreach activities(group)), household assets (land-man ratio, livestock capital, and type of the farmer's house), land attributes (slope category), perception of technology-specific attributes (productivity and soil retention), farm orientation (proportion of income off-farm), and farming system related variables (parcel location in the local climatic zone and the type of land use).

We hypothesize the level of perception of the soil erosion problem to be positively correlated with level of education and age of the household head. More experience and knowledge of the farming system associated with education and age of the farmer is expected to raise perception of the problem of soil erosion and its economic impacts. We also conjecture a positive association between perception and diffusion of information through extension and other channels. The total number of introduced conservation practices that the farmer was aware of during the survey (technology awareness) is used as a proxy for the level of information received through extension support and other routes. Moreover, we expect in-catchment farmers (compared to farmers out of catchment) who frequently meet SCRP staff and closely observe ongoing research activities to be more cognizant of the problem of soil erosion.

The effect of land-man ratios on erosion perception is ambiguous. From a Boserupian perspective (Boserup, 1965), the scarcity of land induced by population pressure would increase the impetus to invest in land quality. One may thus argue that the decrease in the soil erosion level following autonomous investment will reduce the threat of the erosion problem and its perception. From a neo-Malthusian perspective, the opposite effect may be expected. Under a land scarce degraded environment, vulnerability to starvation (or the odds of falling below subsistence needs) increases with a decline in land-man ratios. Poverty-induced intensification of farming following the decline in land-man ratios, may thus elevate erosion to a level easily discernible by the land user. In Andit Tid, we expect the latter effect to be more stronger, thus a decline in land-man ratios is expected to raise erosion perceptions. The effect of livestock wealth on conservation investment and erosion perceptions is debatable. In Andit Tid, grazing is communal and the cost of pasture degradation from higher stocking rates is unlikely to be considered by individual livestock owners. If higher livestock wealth also indicates more specialization into this activity away from erosive cropping activities, the economic significance of erosion will decline. This may lower soil erosion perceptions. Since a parcel's slope also determines erosion potential, we expect a positive effect of this variable on soil erosion perceptions.

Likewise, we expect farmers to be more perceptive of the problem of soil erosion in the *Dega* zone, the major cropping zone in Andit Tid (where a variety of crops could be grown in both short and long rainy seasons) than the frost-prone *Wurch* zone (where only barley could be grown during the short rainy season). Similarly, we expect soil erosion on cropland to be more alarming than erosion on pasture land. Diversification out of agriculture (off-farm income) is expected to lower erosion perceptions. While increasing dependence on non-agricultural activities may reduce farm orientation of the household and lower the economic significance of soil erosion, the reduced pressure on the land may also decrease the level of soil erosion and hence its perception.

4.3. Adoption and level of conservation decisions model

In the adoption (binary logit) and the degree of soil conservation (ordinal logit) models, the following variables were included: soil erosion perceptions, household attributes (education, age, family size, consumer-worker ratio, and attitude), institutional conditioning variables (technology awareness, group, land security), household assets (farm size, land-man ratio, livestock capital, and type of the farmer's house), land characteristics (parcel area and slope), perception of technology attributes (productivity, soil retention, and sustainability), farm orientation, and farming system related variables (parcel location and land use).

As recognition of the soil erosion problem is considered to be vital for soil conservation investments, the 'perception' variable is expected to be strongly associated with retention of conservation structures. As noted above, where market imperfections abound, production and consumption decisions may no longer be separable (Singh *et al.*, 1986; Sadoulet and de Janvry, 1995). This suggests dependence of production (and conservation technology choice) on household-specific attributes, consumption choice, and asset position of the household. For example, education has been shown to be positively correlated with adoption and soil conservation effort (Ervin and Ervin, 1982; Norris and Batie, 1987; Pender and Kerr, 1996). Thus, a positive role for education is hypothesized. The effect of family size may go either way. Imperfections in labor markets imply that households with larger human capital may invest more in conservation. The combined effect of market imperfections in labor, output, and risk markets may, however, lead to a decline in investment. This may be due to several factors: (a) for a given land-man ratio, households with large families may perceive a higher risk of starvation than those with smaller families. If crops fail due to bad weather (e.g. hail storms), households with larger families will suffer more, (b) since land-man ratios do not account for land quality, similar land-man ratios may not imply similar food production potential. Similarly, where consumption smoothing constraints exist, an increase in consumer-worker ratio reduces the ability to meet subsistence needs, and may also increase the personal rate of time preference. Hence, a negative effect of the 'C-W ratio' variable is expected.

Previous research also indicates that older peasants are more likely to reject conservation practices (Norris and Batie, 1987; Gould *et al.*, 1989) and productive practices (Bellon and Taylor, 1993). In the absence of land markets, current values of land are not capitalized into the future and land users face problems in transferring their use rights. Since labor and credit markets are imperfect, older peasants lacking the labor necessary for frequent maintenance of conservation structures may also prefer to remove them. Thus, we expect 'age' to have a negative effect on retention of structures. Peasants with a general positive attitude towards new techniques are also considered to be keen on keeping conservation structures. Missing information about new innovations is often recognized as a deterrent to adoption. Thus, we expect in-catchment households and those with a higher level of awareness about available options to be more receptive of conservation structures (positive effects of Group and Awareness variables). In several studies, insecurity of tenure has been found to be a deterrent to conservation investment (Norris and Batie, 1987; Nowak, 1987; Reardon and Vosti, 1995). In Ethiopia, after the 1975 land reform which provided usufruct rights, land was frequently redistributed by PAs to landless peasants (Rahmato, 1994). This is expected to have attenuated the security of tenure, and we hypothesize 'land security' to have a positive effect on retention of structures.

As noted earlier, rural credit market imperfections imply a positive role of asset holdings of households for conservation investments. Farm size is often correlated with peasant wealth that may help ease the needed liquidity constraint. Previous research also found a positive role of this variable on conservation decisions (Ervin and Ervin, 1982; Norris and Batie, 1987; Gould *et al.*, 1989). Similarly, we envisage a positive effect of this variable. In a land scarce area, the per capita availability of cultivable land is also a valuable asset. Increasing population pressure and degradation of land (Grepperud, 1996), have led to extensification of highland agriculture into marginal frontier areas previously considered unsuitable for cultivation. In many areas, possibilities to extensify have long been exhausted. Since structures occupy part of the scarce productive land[3], often without appreciably improving yields, low land-man ratios may trigger removal of conservation structures. Thus, a positive effect of 'land/man ratio' is expected. Since grass roof houses often reflect poverty, houses with corrugated iron roofs are signs of better off households. Thus the 'type of house' which may indicate the level of wealth (and household's rates of discount) is expected to have a positive effect on conservation.

The effect of livestock holdings on conservation decisions is difficult to hypothesize a priori. Where credit markets are imperfect, livestock wealth may (a) ease capital/cash constraints, (b) reduce the subjective rate of time preference (Holden *et al.*, 1996), and (c) provide security (lower risk) to land users, which may enhance conservation investments. More specialization into livestock away from cropping may, however, reduce the economic impact of soil erosion, and/or increase the availability of manure needed to counter the process of nutrient depletion, and thus lower the need for soil conservation. Parcel slope has been found to positively affect adoption (Ervin and Ervin, 1982; Norris and Batie, 1987; Gould *et al.*, 1989). The 'slope' variable is thus expected to have a positive effect on retention of structures. Peasants also expressed difficulty in turning the ox-plow during cultivation of parcels where structures have been installed. Plowing with a pair of oxen is more difficult on smaller parcels as farming will be squeezed between the structures and the parcel boundary on all sides. Hence, we expect a positive effect of 'parcel area'.

Previous research indicates the significant role of perception of technology attributes in shaping adoption decisions (Adesina and Zinnah, 1994; Adesina and Baidu-Forson, 1995). We also expect peasants' perceptions of technology attributes[4] (productivity, soil retention, and sustainability) to have a positive effect on conservation. The net effect of off-farm orientation on investments in land quality is indeterminate on theoretical grounds (Gould *et al.*, 1989; Reardon and Vosti, 1995). Increasing dependence on non-agricultural activities may lower the economic significance of soil erosion; the reduced pressure on the land may reduce the soil erosion problem; off-farm investment may also crowd out investment resources for land quality improvement. On the contrary, off-farm income may ease the liquidity constraint needed for soil conservation investments or purchase of fertility enhancing inputs. If structures take-up productive land and decrease immediate returns, peasants are more likely to keep structures in less intensively cultivated *Wurch* zone than the main cropping (*Dega*) zone. Thus, a negative effect is expected on the 'location' variable. Since the private cost of erosion on grazing land is limited, we expect peasants to invest more on prime cultivable land than on permanent grazing lands. Hence, 'land use' is expected to have positive effect.

5. Empirical Results

5.1 The perception model

Results of an ordinal logit estimation of the perception model appear in Table 2. The signs of most of the estimated parameters conform to our expectations (exceptions are the group, productivity, and type of house variables). The likelihood ratio goodness of fit test shows a good fit for the model (significant at $P<0.001$ level). Physical erosion potential of the parcel (slope) seems to be the most important determinant of the perception of soil erosion. The higher the slope category of a parcel, the higher the probability that recognition of soil erosion will be above any fixed level. The odds ratio of 3.6 on the slope variable suggests that, *ceteris paribus*, the odds that the perception of soil erosion will be above any given level will be 3.6 times higher for parcels on higher slope categories than parcels on lower slope categories. Farmers' perception of technology-specific traits also seem to be highly associated with recognition of the threat of soil erosion. Farmers who perceive the traditional technique as highly ineffective for retaining soil seem to have higher recognition of soil erosion. For a given level of other regressors, the odds that recognition of soil erosion will be above any fixed level is 2.2 times higher for farmers who consider the traditional technique less effective for mitigating soil erosion. Land being a valuable asset to many rural households in Ethiopia, the ineffectiveness of farming practices in maintaining the productive capacity of their vital resource seems to make them more observant of the soil erosion problem.

The education variable does not significantly shape erosion perceptions. This was not very surprising since most of the farmers in the survey were illiterates and the average level of education was only 1.36 years, a level too low to make any significant impact. But, education and age seem to be positively associated with recognition of the soil erosion problem. Consistent with innovation diffusion theory, access to information about available technological options for soil conservation had a significant effect on perception of the erosion problem. As expected, soil erosion perceptions are negatively affected by increase in cultivable land per capita. The probability that the level of perception of the erosion problem will be below any fixed level also increases significantly (1%) with livestock wealth. If this implies substitution of livestock for erosive cropping practices, its ultimate effect may enhance sustainable land use since highly degraded areas in the highlands are more suited to tree crops and livestock than erosive cropping activities. Lack of markets and institutional support severely hinder evolution of farming systems towards a sustainable system that also improves the welfare of the poor.

An additional variable on the subjective rate of discount was also found to have a significant negative effect on recognition of the soil erosion problem. Consistent with the theory that poverty leads to high discount rates in implicit evaluation of slow-maturing conservation investments (see Mink, 1993; Reardon and Vosti, 1995, Holden *et al.*, 1996), we consider the rate of time preference to have an effect on conservation decisions. Its direct link with recognition of the soil erosion problem is not very obvious. But, it seems that where the day-to-day survival of the household is overriding, poor rural households seem to be less concerned about current rates of erosion and their future productivity impacts. Its removal from the model also lowered the goodness of fit and affected the magnitude of other estimated parameters. Its correlation with other regressors was, however, not very high (the highest was r = - 0.46 with the 'livestock' variable).

5.2 Adoption and level of conservation decisions model

The ordinal logit results for the degree of use of soil conservation practices is given in Table 3. In the first three columns, results from direct use of observed levels of the perception variable is reported. The next three columns present results from a recursive use of predicted levels of soil erosion perceptions. Although the likelihood ratio tests indicate a good fit for both models, other goodness of fit measures (the lower AIC and SC values for the non-recursive model) suggest that the decision to remove or maintain conservation structures seems to be better explained in the non-recursive formulation. This may not, however, invalidate the two-stage conservation decision process since we may have missed important variables in predicting soil erosion perceptions.[5]

Most of the regressors used in this model had signs that comply with our prior expectations. The results show that farmers' decisions to retain conservation structures are positively and significantly related to soil erosion perceptions, attitude towards new technologies, exposure to new practices, per capita availability of cultivable land, parcel area and slope, and productivity of the technology. Similarly, negative significant influences for retention of conservation structures include age, family size, and location of the parcel in the main cropping zone. Some variables (education, group, soil retention, sustainability), however, carry unexpected signs, but they were all non-significant.[6]

Older peasants are more likely to remove structures than younger ones. This indicates that although younger households may have limited experience to detect the erosion problem, they are more likely to adopt conservation practices once they perceive the problem. Family size had a significant negative effect on the decision to retain conservation structures. For a given land-man ratio, households with larger families seem to accept less risk in experimenting with new technologies. Households with positive attitude towards new ideas and techniques, however, seem more likely to retain structures. The proclivity to try new ideas and farming practices may also reflect lower risk aversion (which was not separately measured in this study) by these households.

Access to information about available technological options for abating soil erosion had a significant effect on keeping conservation structures. This may indicate the positive role of extension effort on adoption. Peasants' perceptions of the security of use rights to land also seem to be associated with a higher level of use of conservation structures, but its effect was not statistically significant. This may partly be due to measurement problems as security of tenure was measured in binary units. In Ethiopia, the tenural system of use rights that prohibits land markets is likely to be a disincentive to undertake conservation investments with long payback periods (e.g. tree planting). Even for conservation structures, our results suggest a similar trend, but also indicate the presence of other more binding constraints currently limiting such investments.

A decrease in land-man ratio was closely related to removal of conservation practices. This result also lends evidence to our hypotheses of the strength of the neo-Malthusian scenario in the area. As in much of the highlands, population pressure and degradation of land had led to increasing land scarcity in Andit Tid. In the major cropping zone, fallowing is rarely practiced, and land scarcity has forced peasants to use hand hoes on steep slopes where oxen cannot be used for plowing. As the extensive margin disappears, land-hungry peasants strive to secure subsistence by intensifying production on ever smaller plots. Under increasing subsistence demand, the degradation of land that pursues this kind of labor-led intensification (Lele and Stone, 1989; Reardon and Vosti, 1995) often leads to a poverty-degradation trap that feeds upon each other. As Heath and Binswanger (1996) note, the effect of poverty and population on conservation investments is very much conditioned by the policy environment. Where appropriate policy incentives and technologies are lacking, population pressure per se is insufficient to encourage land conservation. As expected, peasants are also more likely to keep conservation practices on steeper slopes where they perceive higher erosion problems than on shallower slopes. The larger the area of the parcel and the steeper its slope, the higher the probability that structures will be retained.

Peasants' perception of technology attributes (productivity) was also related to increasing level of use of conservation practices. Despite the fact that only 6% of the households consider the new conservation techniques higher yielding, this attribute was found to be significant at 5%. Other things being constant, anticipation of higher productivity will enhance adoption of the new technology. Since structures take-up productive land and maintenance is costly, peasants are very curious about the yield effect of the technology. Interpretation of the odds ratio is similar to the perception model. For example, the odds ratio of 2.86 for the perception variable indicates that, *ceteris paribus*, the probability that all conservation practices will be retained in a parcel is about 2.86 times higher at higher levels of perception than at lower level of perception of the erosion problem. Moreover, farm size and proportion of household income from off-farm sources, appear to be significant in the recursive model. While the effect of farm size was reinforced by removal of land-man ratios in the second stage, increasing reliance on off-farm sources seems to reduce the incentive for land conservation. Similar results were obtained elsewhere (Norris and Batie, 1987; Gould *et al.*, 1989).

The effect of some of the most important variables on the peasants' decisions to retain or remove the technology is provided in Table 4. The probabilities are computed from the estimated ordinal logit model of equation (2). The probability ranges are given by group of peasants and location of parcels at the extreme values of slope, perception, land-man ratios, and perceived productivity of structures at the average values of all other variables. The two rows in the middle of the table present probabilities at the average values of all other variables for the lowest and highest slope categories. For example, at the *Dega* zone, the probabilities for complete removal of structures range from 0.89 (for parcels in the lowest slope category, soil erosion is unrecognized, land-man ratio is lowest, and conservation is unproductive) to 0 (for parcels in the highest slope category, erosion is well recognized, land-man ratio is highest, and conservation is productive). This compares with 0.36 and 0.08 at the average values of the regressors at the lowest and highest slopes. Similarly, the probability of retention of structures ranges from 0.01 to 0.95 while the average values are 0.10 and 0.42. In each location, the effect of slope very much depends on the level of erosion perception, the land-man ratio, and perceived productivity of conservation. Even at shallower slopes, structures are very unlikely to be removed completely on parcels where land users perceive a significant threat of soil erosion. As one moves from the major cropping (*Dega*) zone to the less intensive cropping (*Wurch*) zone, the probabilities of complete removal decrease, while the probabilities of partial removal and retention increase. The same trend occurs as one moves from in-catchment parcels to out-of-catchment parcels within each farming zone.

The results from the estimated binary logit model of equation (7) are presented in Table 5. Most of the signs of estimated coefficients also conform to our hypotheses. The goodness of fit tests indicate a good fit for the model using observed soil erosion perceptions than predicted values; the two models correctly identified about 81.2% and 77.4% of the observed binary adoption variable, respectively. Adoption of conservation structures is positively and significantly related to perception of soil erosion, parcel area and slope, land-man ratio, and technology awareness, while rejection of structures is associated with location of the parcel in the major cropping zone and age of the household head. Estimated elasticities also exhibit high responsiveness of adoption probabilities for the most significant variables. Technology-specific characteristics do not seem to have a significant effect on shaping adoption decisions, perhaps due to the low percentage of farmers who consider introduced technologies as superior in these attributes. A high percentage of income from off-farm sources also seems to have a negative, but non-significant, effect on adoption. Similar results were found in the recursive use of the erosion perception variable.

6. Summary and Policy Implications

In the wake of high population pressure without technological change, increasing extensification and intensification of farming on erodible slopes and marginal lands in Ethiopia has led to extensive degradation of land (FAO, 1986; Grepperud, 1996). With the help of food-for-work incentives, some efforts were launched since the early 1980s to install conservation structures on lands perceived to be erodible in food deficit areas. Peasants, holding use rights to state owned land, were not allowed to remove conservation structures once they have been installed on the parcels they use. However, the coercive approach of past conservation programs faced problems mainly after the introduction of new policies that renounced coercion and favored voluntary participation.

The results indicate that, first, peasant households' conservation decisions are shaped by a host of factors. Adoption of conservation technologies is likely to increase, among other things, with recognition of the erosion problem, slope and area of the parcel, availability and diffusion of information about conservation needs and options, increase in land-man ratios, and anticipation of higher returns with conservation. In our case, adoption is also likely to be lower with increase in age of the land user and family size. The significance of household attributes, preferences, and capital assets in conservation technology choice provide evidence for nonseparability between production and consumption decisions. This is an effect of rural market imperfections. Second, in degraded areas with widespread poverty, autonomous intensification of land use as a response to increasing population pressure may not always lead to increased investments in land conservation. Although households may invest in land quality with increasing scarcity of land, their abilities to cope with increasing population pressure will eventually be exceeded unless appropriate policies and technical change help ease the pressure. In the absence of such interventions, poor rural households can be caught up in a poverty-population-environment trap that may feed upon each other and lead to worsening poverty and resource degradation. Third, there is a strong need to develop conservation technologies that also provide immediate benefits to impoverished households by improving yields. This is one of the most important challenges for soil conservation policy in the future.

The majority of peasants in Ethiopia do not have access to credit facilities and soil amendments like inorganic fertilizers. Institution of incentive structures to promote conservation effort may include, linking farm subsidies and credit facilities with conservation, provision of secure land rights, and integrated extension services whereby conservation remains an integral part of all forms of land use. In the long-term, the need to ease subsistence pressure requires, among other things, technical change, development of the non-farming sector, and curbing population growth. This suggests that the current *laissez-faire* approach to conservation, which primarily relies on market forces and voluntary choices of land users, is unlikely to induce sufficient investment in land conservation. Specific policies addressing the constraints and limitations of peasants through technical change, development of rural markets, and provision of appropriate incentives are required. More research is, however, needed to identify the most efficient ways of promoting land conservation.

End Notes

[1] McFadden (1973) has also shown that the cumulative density of the difference between any two random variables with a log Weibul distribution will be given by the logistic function.

[2] The predicted values from an ordinal logit model give the probability that $Y \leq j$ for a given level of explanatory variables. This required computation of estimated probabilities for each j to calculate expected values according to $\sum_{j=0}^{2} \hat{P}_j(Y = j)$, where $\hat{P}_j$ is the estimated probability for $Y = j$, to obtain predicted values. Since OLS, provided estimates similar to the ordinal logit model, predicted values were generated using this procedure.

[3] According to the soil conservation guideline's (MOA, 1986) definition of slope(%) as vertical interval - VI- (cm) / horizontal distance (m), on a hectare of land of 20% slope, with a VI of 1 m, there will be about 2 km of structures (with about 1 m width) occupying some 20% of the cultivable land.

[4] Peasants were also asked to compare other technology attributes. Responses for crop residue yields were left out due to high correlation with responses for grain yields. In relation to labor and cash demand, loss of productive land, and convenience for plowing, all surveyed farmers preferred their traditional methods over introduced conservation techniques.

[5] This is evident form the low R^2 obtained from the OLS model in Table 2. A model fitted to assess the effect of the unexplained part of perceptions on conservation decisions also showed a significant effect of residual perceptions.

[6] The group variable was significant at 10% level. If this implies a higher propensity for in-catchment farmers to dismantle structures, it may be related to the steep water ways, disliked by farmers as being more erosive and prone to develop into gullies, built as part of the GFJ structures in the catchment. The soil retention variable had an unexpected sign perhaps due to its strong correlation with soil erosion perceptions (see Table 2).

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Table 1. Definition of all the variables used in the perception and adoption models.

Variable	Definition
MODFIC	An ordinal dependent variable measuring the degree of use of conservation practices on a given parcel: 0 if all bunds were removed, 1 if bunds were alternately removed, and 2 if all the original bunds were maintained on a given parcel.
NMODFIC	A dichotomous dependent variable in the logit model: 1 if MODFIC=0 and 0 if MODFIC≥ 1.
Perception	An ordinal variable measuring the perceived level of the parcel's exposure to soil erosion ranging from no risk of soil erosion (0) to high exposure to soil erosion (3).
Education	Number of years of formal education completed. The clergy in the Orthodox Church were considered as having equivalent of 1.5 years of formal education.
Age	Age of the household head in years.
Family size	Family size.
C-W Ratio	The consumer-worker ratio of the household.
Attitude	A dummy for the peasant's attitude towards a new technology: 1 if a desire to try new technologies on own cost is expressed, and 0 if reluctance to new techniques or a desire to wait until other land users have demonstrated its performance is indicated.
Rate of time preference	The peasant's rate of discount estimated from a survey of minimum willingness to accept an amount today instead of 100 Birr (about US $17) in a year.
Group	A dummy variable indicating whether the household has a parcel in the SCRP catchment: 1 if the household has a parcel, 0 otherwise.
Technology awareness	Awareness of the new technologies measured as the total number of new (introduced) conservation technologies known by the peasant.
Land security	An indicator variable for security of land tenure: 1 if the peasant considered he/she will be able to use the parcel at least during his/her lifetime, 0 otherwise.
Land/man ratio	Ratio of cultivable land to family size.
Farm size	The total area of the farm (cultivated land + fallow land + grazing land).
Livestock	Livestock holdings of the household (in oxen equivalents).
Type of house	An indicator variable for the type of the peasant's house: 1 if corrugated iron roof, 0 if thatched grass roof.
Slope	Slope category of the parcel measured as 1 (<10%), 2 (11-20%), 3 (21-40%), 4 (>40%). Local taxonomy of slopes was used after a random ample of 10 peasants in the village correctly identified the local slope gradients as *Meda*, *Tedafat*, *Daget* and *Areh (Gedel)* according to their level of steepness given above. This was persistently checked and clarified to the respondent, as necessary, by the enumerators at the time of the survey.
Parcel area	Area of the parcel in a local unit called *Timad* (approximately 0.25 ha).
Productivity[1]	A dummy for productivity of technology: 1 if the peasant considers output/hectare to be higher with the introduced technology than the traditional practice, and 0 otherwise.
Soil retention[1]	A dummy for the effectiveness of the technology to retain soil: 1 if the peasant considers the introduced technology to be superior, and 0 otherwise.
Sustainability[1]	A dummy for ability of the technology to sustain yields: 1 if the peasant considers the new practice to be more effective in sustaining current yields, and 0 otherwise.
Off-farm orientation	Proportion of household income (net of all variable costs) in 1993/94 from off-farm sources (other than cropping and livestock).
Location	A dummy variable for the location of a parcel in the local agroclimatic zone: 1 if located in *Dega* zone (below 3200 m a.s.l.), and 0 if located in *Wurch* zone (above 3200 m a.s.l.).
Land use	A dummy variable indicating the type of land use on a parcel: 1 if the parcel is a cultivable land, and 0 if it was used as a permanent grazing land.

[1] Most peasants in Ethiopia use traditional soil conservation methods like furrows seasonally made within the field to drain excess water and diversion ditches built up slope to prevent runoff entering cultivated fields. The effectiveness of these methods to hold the soil is generally considered low. Peasants were asked to evaluate traditional and introduced methods for these and other attributes (also see End Note 4).

Table 2.
Ordinal logit (and OLS) results for perception of the soil erosion problem at Andit Tid.

Variable (Dependent Variable: Perception)	Parameter estimates	Wald chi-squared statistic	Odds ratio	OLS parameter estimates	T-ratio
Household characteristics					
Education	0.066	2.286	1.069	0.037	1.740^{a}
Age	0.009	1.253	1.010	0.004	1.031
Rate of time preference	- 0.676	5.889*	0.509	- 0.239	- 1.849^{a}
Institutional factors					
Group	- 0.007	0.001	0.993	- 0.012	- 0.099
Technology awareness	0.546	6.887**	1.726	0.286	2.865**
Household assets					
Land/man ratio	- 0.250	5.652*	0.779	- 0.132	- 2.581**
Livestock	- 0.172	9.784**	0.842	- 0.072	- 2.112*
Type of house	0.002	0.000	1.002	- 0.003	- 0.022
Land characteristics					
Slope	1.281	132.460***	3.599	0.611	13.900***
Technology characteristics					
Productivity	- 0.387	0.721	0.679	- 0.323	- 1.549
Soil retention	0.800	14.937***	2.226	0.434	4.424***
off-farm orientation	- 0.289	0.290	0.749	- 0.239	- 1.849^{a}
Farming system					
Location	0.389	3.769^{a}	1.475	0.179	1.861^{a}
Land use	0.393	0.800	1.482	0.237	1.133
β_0	- 4.870	32.920***			
δ_1	1.800	165.306***			
δ_2	2.853	272.155***			

- 2 Log Likelihood = 201.664; Model df = 14; N = 452
Adj. R^2 = 0.347; F = 16.68 (for OLS model).
^{a}, *, **, *** refer to significance at 10, 5, 1, and 0.1% level, respectively.
Wald chi-squared statistic is the square of the ratio of the parameter estimate to its estimated standard error.

Table 3. Ordinal logit results for the degree of use of conservation practices on a parcel at Andit Tid (N = 452).

Variables: Dep.variable (MODFIC)	Parameter estimates	Wald chi-square statistic	Odds ratio	Parameter estimate[b]	Wald chi-square statistic	Odds ratio
Perception						
Perception	1.053	63.651^{***}	2.86	-	-	-
Predic. perception	-	-	-	1.677	92.926^{***}	5.34
Household characteristics						
Education	- 0.046	0.679	0.96	- 0.109	3.901^{*}	0.89
Age	- 0.039	12.045^{***}	0.96	- 0.023	5.529^{*}	0.98
Family size	- 0.278	9.260^{**}	0.76	- 0.423	56.748^{***}	0.73
C-W ratio	- 0.182	0.396	0.83	- 0.188	0.503	0.85
Attitude	0.530	4.042^{*}	1.70	0.435	3.248	1.41
Institutional factors						
Group	- 0.573	3.099^{a}	0.56	- 0.019	0.005	0.98
Technology awareness	0.855	9.449^{**}	2.35	-	-	-
Land security	0.199	0.211	1.22	- 0.102	0.070	0.91
Household assets						
Land/man ratio	0.629	9.269^{**}	1.88	-	-	1.28
Farm size	0.067	2.047	1.07	0.135	18.219^{***}	1.08
Livestock	0.005	0.003	1.01	-	-	-
Type of house	0.541	3.118^{a}	1.72	0.265	1.024	1.15
Land characteristics						
Slope	0.625	23.464^{***}	1.87	-	-	-
Parcel area	0.209	3.888^{*}	1.23	0.210	4.240^{*}	1.26
Technology characterstics						
Productivity	1.175	3.693^{*}	3.24	0.996	3.385^{a}	2.53
Soil retention	- 0.051	0.036	0.95	-	-	-
Sustainability	- 0.249	0.330	0.78	- 0.044	0.013	0.927
off-farm orientation	- 0.942	1.968	0.39	- 1.001	2.637^{a}	3.538
Farming system						
Location	- 0.768	9.752^{**}	0.46	- 0.729	10.201^{**}	2.082
Land use	0.302	0.345	1.35	0.110	0.055	0.986
β_0	-5.55	16.42^{***}		- 2.31	0.609	
δ_1	2.74	152.98^{***}		2.32	157.02^{***}	
AIC/SC	642/736			719/793		
-2 Log L	302.9^{***}			215.8^{***}		
Model df	21			16		

AIC = Akaike Information Criterion = - 2 Log Likelihood + 2(*k*+*s*) where *k* is the number of explanatory variables, and *s* is the number of ordered values. SC = Schwartz Criterion = - 2 Log Likelihood + (*k*+*s*) Log (N).

^{a}, *, **, *** refer to significance at 10, 5, 1, and 0.1% level, respectively.

[b] Parameter estimates using predicted values of Perception (PREDPER) from the OLS model of Table 1.

Table 4 Estimated probabilities for complete removal, partial removal, or retention conservation structures at a plot level at Andit Tid.

				In Catchment						Out of Catchment					
Slope	Perception	Land-man Ratio	Productivity of Technology	Dega Zone			Wurch Zone			Dega Zone			Wurch Zone		
				J=0	*J=1*	*J=2*	*J=0*	*J=1*	*J=2*	*J=0*	*J=1*	*J=2*	*J=0*	*J=1*	*J=2*
1	**0**	**0.4**	**0**	**0.89**	**0.11**	**0.01**	**0.78**	**0.20**	**0.02**	**0.82**	**0.17**	**0.01**	**0.67**	**0.30**	**0.03**
1	0	0.4	1	0.71	0.27	0.03	0.53	0.42	0.05	0.58	0.38	0.05	0.39	0.52	0.09
1	0	3	0	0.60	0.36	0.04	0.41	0.50	0.08	0.46	0.47	0.07	0.29	0.58	0.14
1	0	3	1	0.32	0.56	0.12	0.18	0.59	0.23	0.21	0.60	0.19	0.11	0.55	0.34
1	3	0.4	0	0.25	0.59	0.16	0.13	0.57	0.29	0.16	0.59	0.26	0.08	0.49	0.42
1	3	0.4	1	0.09	0.52	0.39	0.05	0.38	0.57	0.05	0.42	0.53	0.03	0.27	0.71
1	3	3	0	0.06	0.44	0.50	0.03	0.29	0.68	0.04	0.33	0.64	0.02	0.19	0.79
1	3	3	1	0.02	0.22	0.76	0.01	0.12	0.87	0.01	0.14	0.85	0.01	0.07	0.92
1	***1.61***	***1.76***	***0.062***	***0.36***	***0.54***	***0.10***	***0.21***	***0.60***	***0.20***	***0.24***	***0.59***	***0.17***	***0.13***	***0.57***	***0.30***
4	***1.61***	***1.76***	***0.062***	***0.08***	***0.50***	***0.42***	***0.04***	***0.35***	***0.61***	***0.05***	***0.39***	***0.57***	***0.02***	***0.24***	***0.74***
4	0	0.4	0	0.55	0.40	0.05	0.36	0.54	0.10	0.40	0.51	0.09	0.24	0.59	0.17
4	0	0.4	1	0.27	0.58	0.15	0.15	0.58	0.27	0.17	0.59	0.24	0.09	0.51	0.40
4	0	3	0	0.19	0.59	0.22	0.10	0.53	0.37	0.12	0.56	0.33	0.06	0.43	0.51
4	0	3	1	0.07	0.46	0.47	0.03	0.31	0.66	0.04	0.35	0.61	0.02	0.21	0.77
4	3	0.4	0	0.05	0.39	0.56	0.02	0.25	0.73	0.03	0.28	0.69	0.01	0.16	0.83
4	3	0.4	1	0.02	0.18	0.80	0.01	0.09	0.90	0.01	0.11	0.88	0.00	0.06	0.94
4	3	3	0	0.01	0.12	0.87	0.00	0.06	0.93	0.01	0.07	0.92	0.00	0.04	0.96
4	**3**	**3**	**1**	**0.00**	**0.04**	**0.95**	**0.00**	**0.02**	**0.98**	**0.00**	**0.02**	**0.97**	**0.00**	**0.01**	**0.99**

Where, J= 0, 1, 2 refer to complete removal, partial removal, or retention of conservation structures, respectively.

Table 5. Binary logit results for adoption of soil conservation practices at Andit Tid.

Variable (Dep.Variable: NMODFIC)	Sample means	Parameter estimate	T-ratio[b]	Elasticity at Means[c]	Parameter estimate[d]	T-ratio
Perception	1.61	1.04	6.88^{***}	0.76	-	-
Predicted perception	1.61	-	-	-	1.86	8.76^{***}
Household characteristics						
Education	1.36	- 0.002	- 0.03	- 0.001	- 0.07	- 1.05
Age	48.89	- 0.04	-3.13^{**}	- 0.94	- 0.03	-2.36^{*}
Family	6.30	- 0.14	- 1.56	- 0.41	- 0.31	-5.33^{***}
C-W ratio	1.79	-0.002	- 0.005	- 0.002	0.06	0.18
Attitude	0.64	0.31	1.01	0.09	0.24	0.85
Institutional factors						
Group	0.58	- 0.28	- 0.75	- 0.08	0.13	0.43
Tech. awareness	1.69	0.96	3.09^{**}	0.74	-	-
Land security	0.88	0.57	1.05	0.23	0.04	0.09
Household assets						
Land/man ratio	1.76	0.71	3.26^{**}	0.57	-	-
Farm size	10.12	-	-	-	0.16	3.85^{***}
Livestock	3.89	0.06	0.62	0.62	-	-
Type of house	0.33	0.54	1.54	0.08	0.27	0.89
Land characteristics						
Slope	2.04	0.75	4.70^{***}	0.70	-	-
Parcel area	1.54	0.46	3.16^{**}	0.33	0.38	2.82^{**}
Technology characteristics						
Productivity	0.06	0.14	0.18	0.004	0.45	0.69
Soil retention	0.51	- 0.18	- 0.59	- 0.04	-	-
Sustainability	0.16	0.09	0.16	0.03	0.35	0.76
off-farm orientation	0.14	- 0.94	-1.23	- 0.06	- 0.87	- 1.28
Farming system						
Location	0.70	- 1.17	-3.84^{***}	- 0.38	- 1.09	-4.02^{***}
Land use	0.95	0.25	0.35	0.11	0.13	0.21
Constant		- 4.06	-2.46^{*}	- 1.86	- 1.34	- 1.01
-2 Log L		247.98			186.32	
Model df		20			16	
% right predictions		81.20			77.43	

N = 452

[a], *, **, *** refer to significance at 10, 5, 1, and 0.1% level, respectively.

[b] All the T-ratios are valid only asymptotically.

[c] Elasticity at means is given by $\left(\frac{\partial P(Y=0)}{\partial \bar{x}}\right)\frac{\bar{x}}{F(\beta' x)}$.

[d] Parameter estimates using the predicted Perceptions (PREDPER) from the OLS model of Table 1.

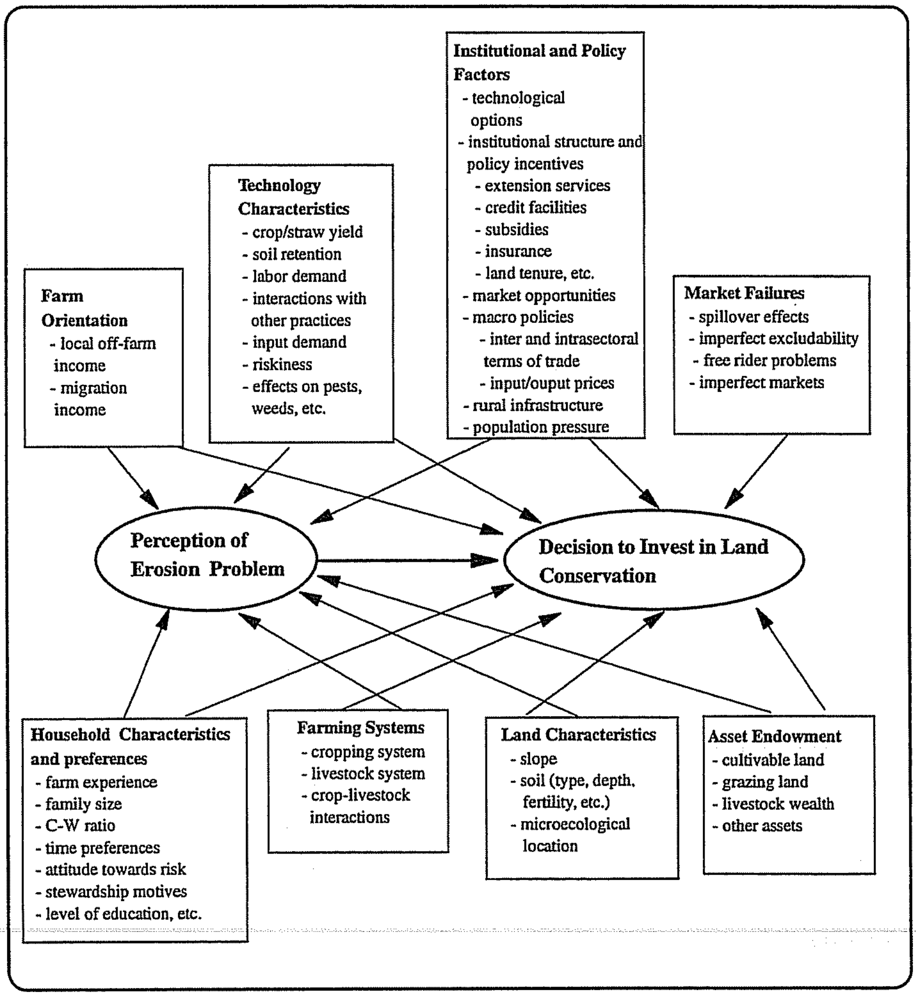

Figure 1. Factors that influence the desire and capacity of land users to invest on land conservation.

A Farm Household Analysis of Resource Use and Conservation Decisions of Smallholders: An Application to Highland Peasant Households in Ethiopia

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Abstract

Peasant households' land use and conservation decisions are likely to be influenced by their dual economic engagement in production (and labor demand) and consumption (and labor supply) decisions. The need to meet consumption requirements from home production, credit and liquidity constraints, etc. within imperfect rural markets are some of the factors that cause nonseparability in production and consumption decisions. This paper develops a nonseparable farm household model based on linear programming to study peasants' conservation decisions. Peasants' short and long-term responses to alternative scenarios that incorporate the user costs of soil erosion at varying levels of average anticipated effects of conservation on production, discount rates, and planning horizons were analyzed. Results reaffirm the strong need to introduce dual-purpose conservation technologies that conserve the soil while also enhancing crop yields in the short-term to make conservation attractive to the smallholder. Under plausible assumptions and constraints faced by peasant households, conservation fails to be a preferred option when average expected yields with conservation are lower or even the same as that without conservation.

Key Words: Land degradation, farm household modeling, linear programming, user costs of soil erosion, productivity effects of conservation.

1. Introduction

In most of the low income countries, agriculture remains to be one of the largest sectors in the economy both in terms of its contributions to the GDP and generating employment. In most African countries, agriculture is the fundamental economic activity accounting on average about 20% to 30% of the GDP. About two-thirds of the sub-Saharan population lives in rural areas and derives its main income from agriculture (World Bank, 1996). The share of the poor living in the rural areas is even larger. In any single year, the agricultural sector in Ethiopia accounts for over 50% of the GDP and provides livelihood for over 80% of the population. As in many sub-Saharan countries of Africa, smallholder farmers cultivating microplots with traditional technologies produce most of the agricultural output. The smallholder sector provides some 90% and 98% of the crop and livestock outputs, respectively. The livelihoods of the largest segment of the population, the smallholders, rely on exploitation of land and other natural resources.

In agriculture-based poor economies, the agricultural sector, therefore, represents the major economy-environment link. In recent years, the interlinked effects of population growth, poverty and agricultural stagnation, and degradation of the resource base and the environment in the developing world are receiving increasing attention (WCED, 1987; World Bank, 1992; Dasgupta and Mäler, 1994; Heath and Binswanger, 1996). Careful analysis of the microeconomic behavior of smallholder farmers is, therefore, central to understanding the roots of environmental degradation and the deepening poverty, and designing of appropriate policies and strategies for reversing the problem.

As smallholder farmers simultaneously engage in production and consumption decisions, the farm household approach has become quite popular in modeling their economic behavior (Barnum and Squire, 1979; Singh *et al.*, 1986a; Delforce, 1994). Most of the farm household modeling to date presumes perfect input and output markets, and independence of production decisions from consumption preferences. The separable framework, postulating a one-way link running from production to consumption, is thus often adopted. However, when some markets are imperfect or non-profit motives (including consumption choices) influence production and resource use decisions, the relevance of the separable approach is often questioned (de Janvry *et al.*, 1991; Delforce, 1994).

In making their land use and conservation decisions, smallholders often face enormous constraints including some endogenous prices due to market imperfections, tenure and liquidity problems, and the need to meet subsistence needs from home production. The farm household perspective, therefore, provides a suitable framework for the study of smallholders' resource use and conservation decisions (Reardon and Vosti, 1992). The use of a farm household approach, and especially a nonseparable framework, in the analysis of resource use and conservation behavior of smallholders is, however, limited. Only few recent studies (e.g. Day *et al.*, 1992; Hwang *et al.*, 1994; Carcamo *et al.*, 1994; Lopez-Pereira *et al.*, 1994) on economics of erosion-control technologies and conservation behavior of small farmers have been framed in the light of the farm household framework, though not explicitly so.

This study develops a nonseparable farm household model for analysis of resource use and conservation decisions of smallholders in the Ethiopian highlands. Production and consumption decisions are modeled interdependently using a nonseparable whole farm linear programming model. The model is used to analyze the short and long-term effects on consumption, production, and conservation decisions of farm households resulting from changes in (a) the productivity of conservation technology, (b) internalizing the on-site user cost of current soil erosion at varying rates of discount, and (c) capital/credit constraints for fertilizer purchase[1]. The analytical approach used, the results and conclusions derived, are likely to have a wider relevance to smallholder agriculture and resource use problems elsewhere.

The rest of the paper is organized as follows. Section 2 provides a description of the study site and the production system in the area. Section 3 develops the analytical model used. Section 4 presents the analytical results and discussions. The last section provides concluding remarks and policy implications for sustainable agricultural development in smallholder-based economies.

2. Smallholder Farming and Resource Use in the Highlands

The Ethiopian highlands, areas over 1500 meters above sea level (m a.s.l.), constitute half of the East African highlands and cover close to half of the area of the country (Getahun, 1978). About 88% of the country's population, over 95 % of the regularly cultivated lands and about 75% of the livestock population are concentrated in these areas (FAO, 1986). Vast areas of the highlands have been classified as suffering from severe to moderate degradation (ibid.). In much of Ethiopia, the level of use of purchased yield-increasing inputs is very low. Increasing intensification and continuous cultivation on sloping lands without soil amendments and conservation practices posit serious threats to land productivity. Due to lack of technical change and degradation of the resource base, the productivity of both crops and livestock is very low.

The data for this study comes from a large socio-economic survey that was conducted by the author in 1994 in Ada district, East Shewa. A stratified random sample of 120 households were surveyed in three neighboring Peasant Associations (PAs) (Hidi, Borer Guda, Hora Kilole) located some 25 km from Debre Zeit, the main town on the Addis Abeba-Nazareth highway. A large set of data related to consumption, production, and conservation decisions of peasant households was generated. The average family size was 5.3 persons with a consumer-worker ratio of 1.62 (4.7/2.9).[2]

The smallholder production system in Ada is typical of the traditional mixed farming system in the highlands. More than half of the agricultural land falls into the high potential cereal-livestock zone (Mukasa-Mugerwa, 1981). Due to its proximity to the major cities, product and input markets are relatively well developed. The altitude at the survey site ranges from 1900 to 2100 m a.s.l., and the annual rainfall (for 26 years, 1959-1994, with complete data) at Debre Zeit, averaged 830 mm with a coefficient of variation of 17%. The rainfall pattern is generally unimodal with over 70% falling between June and September. Some 20% of the rains fall in the short rainy season (March to May). Agriculture is rainfed, but despite the relatively low level of precipitation, drought and crop failures are uncommon. Land is cultivated at the onset of the rainy season using a pair of oxen and traditional implements. Land cover during this period is poor, bunding or terracing is not practiced, and erodible soils on the slopes are easily washed down through torrential downpour.

The surveyed smallholders cultivate a number of parcels distributed mainly over two slope and soil types: the red soils on sloping uplands, and vertisols on shallow slopes at the foothills (lowlands). The average land holding is about 2.25 ha, with 1.25 and 1 ha on uplands and lowlands, respectively. Fallowing is very rare. A number of cereals and pulses are produced, but only teff and wheat are grown on both types of land. Teff is the major staple and cash crop. The white variety with highest market value is mainly produced for sale while the red variety is mainly grown as a staple. Better off households also maintain some livestock. Oxen ownership is vital for crop production and may serve as a good wealth indicator. This is mainly so because land has frequently been redistributed according to family size since the 1975 land reform. Smallholders were, therefore, stratified into four groups based on the number of owned oxen (0, 1, 2, >2). The average cropping and livestock production activities are summarized in Table 1.

3. Conceptual Framework and Analytical Model

A household farm is a composite of the consumer, the laborer, and producer's households (Nakajima, 1986; Sadoulet and de Janvry, 1995) and thus the smallholder is likely to respond to changes that affect any of its attributes as producer or consumer/worker. If all markets exist, all prices are exogenous and decisions can be taken sequentially. This suggests that production and labor demand decisions can be de-coupled from consumption and labor supply decisions, and the level of income achieved in production will serve as the only hinge between the two aspects of the farm household's decisions (Singh *et al.*, 1986b). Most of the farm household modeling developed to date pursues this separable or recursive approach. However, separability implies that production and labor demand decisions are insensitive to consumption preferences and household characteristics, and activity choice is entirely determined by profit motives as dictated by market prices.

When some markets fail, production and consumption decisions are interdependent and are linked through endogenous prices that satisfy the subjective equilibrium of the household. Where market imperfections are not uncommon and goals other than profit maximization are likely to affect production decisions, the relevance of the separable approach is questionable (de Janvry *et al.*, 1991; Delforce, 1994). Thus, a pure profit maximizing framework often fails to reflect real patterns of cropping and resource use in smallholder farming (Singh and Janakiram, 1986; Delforce, 1994). This is mainly because production and resource use decisions are likely to be affected by non-profit considerations such as preference for home production of staple food, leisure consumption and other goals. This may also be related to risk-aversion and/or credit and liquidity constraints that make some prices endogenous to the household.

In developing a nonseparable model, a representative household is assumed to have four major goals: maximization of net income, self-sufficiency in major staples, generation of cash sufficient to meet various needs, and achievement of acceptable levels of leisure. A linear programming (LP) framework, despite some of its known limitations, was chosen mainly because of its suitability for incorporating multiple goals, modeling multiple production activities in highly constrained production systems, and for its relative ease to carry out policy analysis in relation to resource use and conservation decisions of farm households. Considerable difficulties were also envisaged in estimating a joint production and consumption system of a nonseparable household using the cross-sectional data of a single cropping year. Nevertheless, econometric models also have limited use for policy analysis when conditions are varied beyond the range of the data used for estimation. Similar observations have prompted previous researchers to use an LP for farm household modeling (e.g. see Ahn *et al.*, 1981; Singh and Janakiram, 1986; Bezuneh, 1988; Delforce, 1994).

Major activities in the LP model included crop production on two land types (upland and lowland) with three levels of fertilizer use (no use, average current levels of use, and recommended levels of use) and two land management options (with and without conservation); crop sale and consumption; seasonal family labor use for production (on- and off-farm) and leisure; seasonal labor hiring; livestock production, sale and consumption; and activities for accounting the future productivity impacts of current soil erosion. The model constraints included limits on owned and rented land, labor (including leisure), oxen power, subsistence needs, animal feed requirements, capital/credit for fertilizer, cash income, and restrictions on crop rotations. Constraints on subsistence consumption needs were defined in terms of minimum nutrient requirements (carbohydrates, protein, and fat). Taste and diversity constraints reflecting observed patterns were imposed to ensure that the pattern of consumption closely reflects actual preferences. Purchasing options for major staples were excluded to ensure satisfaction of the self-sufficiency goal. Feed requirements for livestock were defined in terms of dry matter, but shortfalls from own production of crop residue feed were allowed to be met through purchases. Limits on land renting were set at a maximum of 1 ha (0.5 ha each in the uplands and lowlands). This is almost twice higher than the average area rented among the surveyed households. A total of 202 activities and 150 constraints were specified. The whole farm model then identified a production plan that maximized annual net returns defined as current net returns (on-farm and off-farm) less the present value of future income loss caused by yield losses resulting from current soil erosion (user costs) subject to various farm-level resource supply and behavioral constraints. The highly aggregated structure of the LP model is given in Table 2. Mathematical representation of the model is given in Annex 1.

Alternative methods for incorporating consumption and leisure requirements into programming models are described by Hazell and Norton (1986, pp 63-66). We preferred the approach that captures the effect of income on consumption and leisure choice by introducing an income activity in which the negative of the marginal propensities to consume food and leisure are entered into the corresponding consumption and leisure constraints. A system of Engel equations was estimated for major categories of consumption to obtain the coefficients on the income activity corresponding to consumption constraints (see Appendix A). The categories in the demand system include teff, other cereals, animal protein, other purchased food, non-food purchased goods, purchased services (education, health, transport, etc.), and leisure. In estimating the Engel system, full income was used to link production and consumption decisions, while household characteristics were used to capture part of the non-income effect on consumption.

Allocation of family labor into on-farm, off-farm and leisure activities was incorporated seasonally. Seven periods reflecting the cropping calendar were defined and seasonal labor constraints showed family labor endowments in each period. Since Orthodox Christian peasants in the study area (similar to other areas in Ethiopia) observe some 160 religious holidays each year, the total family labor days available exclude these days that prohibit field activity. Seasonal labor hiring options were introduced to meet seasonal scarcities by hiring additional labor. Availability of oxen days for traction were also defined seasonally similar to family labor reflecting religious norms.

Levels of gross soil erosion from each production activity on two types of land and two land management options (see Appendix B) were estimated using the modified USLE adapted for Ethiopian conditions (Hurni, 1985). Measurements taken on different transects during the survey have given values for the slope length and slope gradient factors of the USLE. Since soil erosion on vertisols was considered to be unimportant for the land user, a conservation option was defined only for erodible soils on sloping lands on the hills (uplands). From a number of soil conservation options (mainly structural measures) recommended for different agro-climatic zones in Ethiopia, level (contour) bunds were identified (in consultation with technicians) to be the most suitable for low-to-medium rainfall areas like Ada district. Due to scarcity of stones within or near the cultivated fields, preference is also given for soil rather than stone bunds. In lack of better socio-economic data on conservation options, labor requirements for construction and maintenance of soil bunds were specified according to the work norms of the Ministry of Agriculture (MOA) for conservation activities (MOA, 1995). Construction and maintenance of soil bunds is assumed to be carried out during the slack seasons between January and May.

The effect of soil erosion on crop yield was estimated from a production function estimated for the major crop (teff) based on time series data collected by the Soil Conservation Research Project (SCRP) in other areas of the highlands (Anjeni in Gojjam). From a number of functional forms estimated with regressors including soil depth, slope, rainfall, and frequency of plowing before planting, the translog model provided the best fit (adj. R^2=0.64). A loss of 1 cm of soil depth (about 100 tons of soil) per ha was estimated to reduce yields by 45 kg on red upland soils and 20 kg on vertisols (see Appendix C). The negative of discounted values of all future productivity losses resulting from a unit of current soil erosion (the marginal user costs) are thus entered on the soil erosion activities for the two land types in the objective function.

All activity budgets and farm-level resource supplies were specified for a representative household that reflects the average of 120 households surveyed[3]. Own area of cultivable land was set at the average of 1.25 ha on uplands and 1 ha on lowlands. The average oxen holding of 1.78 was, however, rounded to the nearest integer that also represents the largest group of peasants (those with a pair of oxen). The three levels of fertilizer use were specified for all cereals in order to allow plausible adjustments in resource use in response to changes in policy variables. Although three levels may be insufficient, they serve as a means of piece-wise linear approximation to a concave yield response function. Crop responses to the three levels of fertilizer use are determined from the survey data and fertilizer response equations estimated for the study area from a nation-wide fertilizer trial conducted on major cereal crops (Ho, 1992). At present, no fertilizer recommendations exist for pulses and peasants do not apply fertilizer on these crops.

In the analyses of the short-term responses, only the initial labor requirements for installing conservation structures (100 mandays ha^{-1}) and end of the year maintenance (20 mandays ha^{-1}) were included. In modeling the long-term response, the stationary equilibrium was simulated using average labor requirements over 15 years (for initial installation and annual maintenance thereafter). In the capital constrained models, in addition to owned capital of 100 Birr, the household is assumed to have access for formal credit (≤300 Birr) at 12% interest and some informal credit (≤75 Birr) at 90% interest. These capital/credit constraints are in line with the credit markets prevalent in 1994 and reflect average rates of fertilizer use.

4. Results and Discussions

4.1 Short-term responses to productivity effects and user costs

Investment in conservation structures is expected to lower soil erosion rates. But, at least in the short-term, crop yields, *ceteris paribus*, might decrease, remain the same or increase depending on the interactions with biophysical conditions and the amount of productive land occupied by structures. For example, assuming a vertical interval of 1 m (recommended level is 2.5 times the rooting depth), on a 20% slope, the area of productive land lost due to structures could reach up to 20% and the proportion rapidly increases with slope. Apart from loss of productive land, peasants also often complain that soil and stone bunds (a) interfere with traditional practices of crisscross plowing, especially when the distance between bunds is short, making turning the plow difficult, and (b) harbor notorious rodents (e.g. rats) and weed pests. Some 83%, 87%, and 25% of the respondents indicated, respectively, loss of productive land, working inconvenience, and pest problems as deterrents for adoption of conservation structures. Our surveys in other areas of the highlands, where conservation structures were introduced in the past, also indicate that 74% (Anjeni, East Gojjam) and 92% (Andit Tid, North Shewa) of the surveyed households assess yields with conservation to be lower than without conservation[4]. In Anjeni and Andit Tid, areas with high rainfall, the problem of water logging behind the structures has also been reported.

Three alternative scenarios for the effect of installing conservation structures on yields from the peasants' perspectives were included: average anticipated yields with conservation are (a) 20% less than without conservation (I), (b) no different from without conservation (II), and (c) 20% more than without conservation (III). The analytical results for the short-term response of the farm household to the three levels of productivity of conservation and internalizing the on-site user costs of soil erosion at differing discount rates are presented in Table 3. In the basic models, no user costs of current soil erosion are internalized, and conservation structures enter the solution only when conservation is yield-enhancing. In the to motivate and guide the peasant towards sustainable land management and increased conservation in the long-term. Short of such persuading mechanisms to install conservation in the near-term, the steady state level of conservation may remain unattained.

When conservation is perceived to be productive, complete conservation may occur in the long-term even when no user costs are accounted for or accounted at the estimated average discount rate of 54%. This compares with 86% and 87% conserved, respectively, in the short run. This implies that when structures serve as a multi-purpose technology, peasants (including those who may not be interested in future productivity impacts of current erosion) may fully adopt conservation. In this case, no additional incentives are required other than enforcing nonattenuated rights to land. Insecure rights to land could shorten the planning horizon (and the fear of expropriation at any time within the planning horizon may also raise the discount rates), thereby preventing the smallholders from adopting a long-term perspective in making their land use decisions. This can hinder attaining the steady state equilibrium. In Ethiopia, land is a state property and the smallholder retains only use rights. Despite the illegality of land markets, currently, insecurity of land rights does not seem to be a crucial deterrent to installation of conservation structures (Shiferaw and Holden, 1996) perhaps due to other more binding constraints like poverty, imperfect rural markets, and lack of appropriate incentives[5]. Moreover, as in short-term responses, the steady state also indicates substitution of wheat for teff as more weight is given to long-term land productivity loss. A rise in the level of internalized user costs and a fall in income also reduce leisure demand and increase family labor supply, thereby depressing the need to hire in labor.

4.3 Effect of fertilizer cash/credit constraints

The results discussed so far were capital unconstrained for purchasing fertilizer. The expenditure on the income maximizing level of fertilizer use was thus higher than the average observed expenditure on this input. The level of income achieved for the representative household farm was also higher since the model chooses the recommended level of fertilizer which is higher than the current level of use. An unconstrained use of fertilizer may also obscure the impact of future productivity loss thereby deluding the land user to overlook user costs and the need to mitigate current soil erosion (Shiferaw, 1996). In order to investigate this effect on the short-term responses of the farm household, cash/credit constraints reflecting the current level of expenditure on fertilizer were imposed. Table 5 presents the results of the cash/credit constrained model. The user costs internalized in A, B, C, D, and E are similar to that in Table 3 and 4. The cases in F, G, and H were, however, used to examine the effect of changes in fertilizer prices while user costs are internalized at the average estimated rate of discount (as in B).

When conservation technology is perceived as counterproductive, a cash/credit constraint does not force conservation into the optimal solution in all cases except E (5% rate of discount). With a capital constraint, 52% of the uplands will be treated with conservation which compares with only 39% in the capital unconstrained model. The fall in household income due to constrained use of fertilizer and the reduction in leisure consumption release some family labor for conservation as the level of internalized user costs increase. The decline in income and on-farm productivity of labor when high weights are given to future productivity loss compel the household to supply increasing family labor off-farm. The total area of teff and its share on uplands decrease as more weight is given to user costs. Likewise, area of the less erosive crop (wheat) increases, and a progressive shift in cereal production to less erodible soils occurs. The simulations F through H indicate that a rise in the 1993/94 fertilizer prices (e.g. after devaluation and removal of input subsidies) in the face of a capital constraint will not induce any conservation, but gradually shift cereal production from uplands to lowlands. The effect of a rise in fertilizer prices is initially compensated by the increase in wheat area, but the area under pulses, grown without fertilizer, would displace wheat as the input price rises further. As returns to family labor on-farm fall and threaten livelihood, the household will reduce leisure time and increase both on- and off-farm labor supply.

When anticipated yields with conservation are perceived to be no better than without conservation, at the average estimated rate of discount, conservation structures would be installed on 16% of the cultivated uplands. This compares with no conservation in the capital unconstrained model. Constrained use of fertilizer lowers the returns to labor and reduces leisure demand which will help release some labor for use in conservation. The fall in income and the increase in user costs also make mitigation of soil erosion cheaper than the loss of future land productivity due to current soil erosion. As the user costs increase, the rise in opportunity cost of labor and the limited possibilities for adjustment of cropping patterns under the capital constraint reduce the rate of conservation until it approaches what was achieved in the unconstrained case. The initial positive effect of capital constraints to encourage conservation thus disappears with a rise in internalized user costs. Under capital constraints for fertilizer, a rise in fertilizer prices above 50% forces the household to divert labor used for conservation to expansion of cultivated land (and hence on-farm labor supply) and generation of income off-farm. Thus, conservation disappears in cases F through H, and results are similar to that under case I.

When conservation is yield-enhancing and the land user is not accounting for user costs, the cash/credit constraint for fertilizer depresses adoption of this technology. The share of conserved uplands falls from 87% in the unconstrained case to 48% in the constrained model. This suggests that despite the positive productivity and soil-conserving effects of the technology, its adoption would be limited by lack of cash/credit for a complementary input (fertilizer). This conservation depressing effect of a credit/cash constraint, however, diminishes as the land user begins to account for the user costs of soil erosion. For example, when the user costs are internalized at a discount rate of 54%, the level of adoption of conservation structures on erodible lands in cases with or without a capital constraint would almost be the same. A further increase in the level of internalized user costs leads to complete adoption of conservation practices on all erodible lands. Unlike case I and II, a rise in user costs initially increases area under teff mainly because the crop is grown on lands treated with conservation (>85%) that would enable sizable reductions in soil erosion. A further increase in user costs, however, displaces teff in favour of wheat. A rise in fertilizer prices, and the resulting decrease in leisure demand and opportunity cost of labor in farming, improve the share of upland under conservation from 85% before the price change to 93% with doubling of these prices. Further increase in input prices would, however, raise the shadow value of subsistence while the cash income constraint also begins to be strongly binding. Thus, the household gradually withdraws from conservation as fertilizer prices soar and channel its labor into an offsetting area expansion to satisfy consumption and cash income constraints. This is unlike the situation in the unconstrained model in which adoption of conservation consistently increases (in all cases I, II, and III) at least up to 400% rise in the price of fertilizer. The positive effect on conservation of a rise in the price of a productive input in the unconstrained case is also consistent with theoretical findings (Shiferaw, 1996).

5. Summary and Some Policy Implications

One of the manifold challenges that poor countries with fast growing populations are facing today is the deterioration of the resource base and reduction of the food production potential of agricultural land. Several attempts to abate the soil degradation problem through conservation programs in the past have often fallen short of expectations (Lutz *et al.*, 1994). Smallholders' production and land conservation decisions are likely to be influenced by factors related to their dual nature as units of consumption and production. Soil erosion reduces the future productivity of agricultural land, and privately optimal conservation may not occur when on-site costs of production activities are not sufficiently internalized. High discount rates and short planning horizons contribute to this effect. Subsistence pressure (food insecurity) and insecurity of land tenure are some of the major factors that lead to high rates of time preference and short planning horizons. Even if smallholders are aware of the user costs and are willing to internalize them, the productivity impact of conservation and its influence on their short-term welfare influence the level of conservation achieved.

In the short run, when the smallholder is not internalizing the user costs of current production, no land conservation is likely to occur unless conservation technology is enhancing productivity. When anticipated returns with conservation are lower or the same as without conservation, the lower yields and substantial costs of installation prohibit smallholders from adopting conservation structures. Under the labor and other costs assumed for installing soil bunds, conservation is quite unlikely to occur even when the user costs are internalized at the average estimated rates of discount (54%) unless conservation helps to boost yields. Only if discount rates are as low as 5 to 10% would some conservation become part of the optimal farm plan. This may explain the general lack of conservation in the study area. It also suggests that policies to enhance soil conservation should look for new techniques that are both less costly and play the dual purpose of countering erosion while also raising yields. Where this is lacking, society may have to look for other incentives (carrots and sticks) to persuade the land users to install conservation practices.

Under plausible assumptions, even in the long run, conservation will not be part of the smallholders' optimal production plan when it reduces the productivity of the land. Only when the user costs are internalized at low rates of discount (less than 10%) would conservation enter the optimal plan. However, such a low level of discount seems to be justifiable from the viewpoint of society rather than that of the representative household. When anticipated returns with conservation are no different from without conservation, zero conservation is also likely to be optimal unless user costs are sufficiently internalized. Although widespread adoption of conservation appears to take place in the long run when user costs are accounted at average estimated rates of discount, this may not be achievable unless some incentives are used in the short run to induce the land user to embark on conservation. Apart from secured rights to land, extensive educational and outreach programs may also be desirable to increase the smallholders' awareness of the user costs and encourage community effort and collective action to counter the soil erosion problem. When conservation adds to current yields, all erodible lands seem to be treated with structures regardless of the land user's concerns for user costs.

The effect of a fertilizer cash/credit constraint on production and conservation decisions also depends on the productivity of conservation practices. When conservation is either yield-depressing or neutral, relaxation of the cash/credit constraint for fertilizer seems to decrease conservation. This indicates to the need for cross-compliance policies that link input and credit subsidies with the requirement to install conservation. When conservation is yield-enhancing, such a constraint depresses conservation when user costs are not internalized, but only until user costs become part of smallholders' land use decisions. A rise in fertilizer prices in the face of a capital constraint seems to slightly encourage conservation when the technology adds to land productivity, but it eventually declines as input prices rise further. When conservation is yield-neutral, a rise in fertilizer prices under the capital constraint crowds out conservation very quickly. Thus, without provision of sufficient credit to smallholders, the recent soaring of fertilizer prices following structural adjustment programs and removal of input subsidies is likely to discourage conservation.

End Notes

[1] The effect of a number of economic incentives like cross-compliance, cost-sharing, technical change, and price policies on resource use, conservation and consumption decisions of smallholders is explored in the next paper. Also see Shiferaw and Holden (1997).

[2] The major survey questionnaire, prices of agricultural output (averages of dry and wet seasons), average crop yields, average fertilizer use, and the cropping calendar in Ada district are attached at the end of the manuscript (see end of Paper IV).

[3] Since the percentage of the four categories of peasants in the three PAs is slightly different (25%, 16.6%, 34%, and 24.4% for those without oxen, with one oxen, with two oxen, and more than two oxen, respectively), the average of the surveyed peasants (30 in each group) will slightly overestimate the average of all households.

[4] Most highland smallholders in Ethiopia including those in our study area use traditional conservation practices like furrows made within the field to drain excess runoff, and at times, diversion ditches built up slope to prevent runoff entering cultivated fields. Data from preliminary studies conducted by the Soil Conservation Research Project (SCRP) in Andit Tid and Anjeni on experimental plots with different conservation options, where the traditional techniques are used as a control, show that rates of soil loss and runoff are up to twice larger on plots treated with traditional methods than other introduced methods. Hence, the effectiveness of these conventional practices in mitigating the soil erosion externality is generally regarded to be limited.

[5] Insecurity of rights in land may, however, be vital for land-improving and conservation investments with long gestation periods (e.g. tree planting). This observation on the role of land tenure is based on "retention or rejection" of conservation structures that may not have a span of over 15 years. Such technologies introduced through compulsory systems in the past were not also suited to all land types.

Appendix A.

A system of Engel equations estimated for different consumption categories in Ada district[1]

Commodity	Regressors	Parameter Estimate	T-ratio	Elastictiy at Means
	Sex	-152.5	-0.62	-0.08
Teff	Age	1.2	0.25	0.03
$\beta_0 = 306$	Education	-39.8	-0.93	-0.03
	Consumer unit	71.5	1.56	0.21
	Full income	0.2	5.24	0.67
Other cereals	Sex	132	1.48	0.29
(wheat, barley, etc.)	Age	-3.7	-2.05	-0.43
$\beta_0 = 159$	Education	-36.0	-2.29	-0.10
	Consumer unit	-63.0	-3.40	-0.73
	Full income	0.11	8.03	1.58
Pulses	Sex	-34.3	-0.42	-0.08
(faba beans, field	Age	-3.0	-1.83	-0.39
peas, chick peas,	Education	5.5	0.37	0.01
rough peas)	Consumer unit	101.7	5.36	1.33
$\beta_0 = -10$	Full income	.0099	0.71	0.15
Animal Foods	Sex	- 48.6	-1.16	-0.20
(chicken, eggs, beef,	Age	- 0.9	-1.07	-0.19
sheep, goat, butter)	Education	8.2	1.13	-0.04
$\beta_0 = 55$	Consumer unit	2.8	0.33	-0.06
	Full income	0.04	5.87	1.04
Other Purchased	Sex	- 15.7	-0.53	-0.06
Foods	Age	- 0.8	-1.25	-0.16
(e.g. cooking oil,	Education	- 3.3	-0.63	-0.02
sugar, salt, etc.)	Consumer unit	15.0	2.40	0.33
$\beta_0 = 81$	Full income	0.02	4.30	0.54
Non-Food	Sex	110.4	0.99	0.11
manufact. goods	Age	- 5.3	-2.37	0.29
(includes tea and	Education	2.7	0.14	0.01
coffee)	Consumer unit	- 15.1	-0.68	-0.08
$\beta_0 = 232$	Full income	0.15	8.83	0.98
Services	Sex	8.1	0.08	0.05
(transport, health,	Age	- 0.5	-0.55	-0.15
education, house	Education	6.9	0.90	0.05
maintenance, etc.)	Consumer unit	-15.5	-1.70	-0.5
$\beta_0 = -5$	Full income	0.04	5.96	1.59
Leisure	Sex	247.1	0.97	0.15
$\beta_0 = -107$	Age	7.0	1.24	0.23
	Education	-163.1	-2.98	-0.14
	Consumer unit	-160.5	-3.00	-0.54
	Full income	0.338	8.95	1.36
Other Expend.	Sex	- 246.5	-0.83	-0.47
(church, grain mill,	Age	5.9	0.96	0.60
community self-help, etc.,)	Education	218.9	3.83	0.55
	Consumer unit	63.0	1.22	0.63
$\beta_0 = -713$	Full income	0.1	2.53	1.19

[1] Sex, age, and education refer to the household head (Sex =1 when male, age is in years, education in years of formal education). Consumer unit is the standardized number of consumers in the household. The dependent variable is annual expenditure on the specific consumption category.

Appendix B.
Soil Loss for two types of land in Ada district estimated with the Universal Soil Loss Equation (USLE) Adapted to Ethiopia (Hurni, 1985).

$A = R*K*L*S*C*P$

A = Soil loss (tons/ha/year)
R = Rainfall Erosivity Factor
K = Soil Erodibility Factor
L = Slope Length
S = Slope Gradient
C = Land Cover Factor
P = Land Management Factor

I. Without Conservation							II. With Conservation (Level Bund and Level Fanja Juu)					
	Teff		Other Cereals		Pulses		Teff		Other Cereals		Pulses	
Factor	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland
R	430.24	430.24	430.24	430.24	430.24	430.24	430.24	430.24	430.24	430.24	430.24	430.24
K	0.25	0.15	0.25	0.15	0.25	0.15	0.25	0.15	0.25	0.15	0.25	0.15
L	2.10	3.50	2.10	3.50	2.10	3.50	0.60	1.20	0.60	1.20	0.60	1.20
S	1.78	0.40	1.78	0.40	1.78	0.40	1.78	0.40	1.78	0.40	1.78	0.40
C	0.25	0.25	0.18	0.18	0.15	0.15	0.25	0.25	0.18	0.18	0.15	0.15
P	0.75	0.75	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.90	0.90
Soil Loss	**75.56**	**16.94**	**52.89**	**11.86**	**45.33**	**10.16**	**25.90**	**6.97**	**18.13**	**4.88**	**15.54**	**4.18**

Appendix C.
The Translog production function:

$$\ln Y = -1203.12 + 20.2 \ln (TIME) + 134.3 \ln (FPLOW) + 6.69 \ln (SODP) - 10.5 \ln (SLOPE) + 290.5 \ln(RFALL)$$

(0.0001) (0.01) (0.0001) (0.04) (0.07) (0.0001)

$$+ 0.69 \{\ln (TIME)\}^2 - 0.58 \{\ln (PLOW)\}^2 + 0.134\{\ln (SODP)\}^2 + 0.18 \{\ln (SLOPE)\}^2 - 17.22 \{\ln (RFALL)\}^2$$

(0.0001) (0.25) (0.1) (0.08) (0.0001)

$$+ 0.33 \ln (TIME) \ln (SODP) + 0.22 \ln (SLOPE) \ln (SODP) - 1.03 \ln (RFALL) \ln (SODP) - 0.39 \ln (PLOW) \ln (SODP)$$

(0.07) (0.1) (0.15) (0.13)

$$+ 1.03 \ln (SLOPE) \ln (RFALL) + 0.54 \ln (SLOPE) \ln (PLOW) - 17.78 \ln (RFALL) \ln (FPLOW)$$

(0.18) (0.22) (0.0001)

N = 184 harvest samples, Adj. $R^2 = 0.64$

Where *Y* is teff yield in ton ha^{-1}
TIME is the index of time (1-10)
FPLOW is the frequency of plowing to planting.
SODP is the soil depth in cm.
SLOPE is slope gradient in per cent.
RFALL is annual rainfall in mm.

The marginal user cost of a cm of soil depth was estimated assuming an average soil depth of 50 and 100 cm, and slope of 20% and 5% for upland and lowland soils, respectively. The average teff yield of 1.2 tons ha^{-1}, plowing frequency of 6, and rainfall of 800 mm $year^{-1}$ are also used. Due to some problem of multicollinearity, all the interaction terms with soil depth were used although they were not highly significant. The values in parenthesis under the parameter estimates are the p-values. At the current levels of soil erosion, the estimated loss of 45 kg and 20 kg cm^{-1} of soil depth amount to 2.8% and 0.3% productivity decline $year^{-1}$ on upland and lowland soils.

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Table 1. Smallholder production activities in Ada district.

Crop production (*kert*)[1]				Livestock holdings	
Crops	Upland	Lowland	Total area	Animals	Heads
White Teff	2.18	1.06	3.24	Cows	0.83
Mixed Teff	0.27	0.33	0.60	Oxen	1.77
Red Teff	0.79	0.99	1.78	Heifers	0.47
Wheat	0.51	0.43	0.94	Bulls	0.38
Barley	0.16	-	0.16	Calves	0.70
Field peas	0.12	-	0.12	Sheep	0.65
Faba beans	0.58	-	0.58	Goats	1.30
Lentils	0.07		0.07	Donkey	1.00
Chick peas	-	0.60	0.60	Horses	0.07
Rough peas	-	0.37	0.37		
Total area cultivated	4.67	3.78	8.46		

[1] *Kert* is the local area unit in the study area. The average area of some 20 sample plots measured during the survey indicates that a *kert* is approximately 0.3 hectare.

Table 2. An aggregated structure of the inseparable farm household model[1].

	Produce crops	Sell crops	Consume crops	Use own seed	Buy Seed	Buy fertilizer / animal feed	Hire in/out land	Soil erosion	Family labor on farm	Family labor off-farm	Labor hiring	Leisure	Keep breeding stock and oxen	Sell livestock	Consume livestock	Income	Relation	RHS
Objective	+C				-C	-C	-/+C	-C		+C	-C		+/-C	+C				MAX
Land	1						-/+1										<=	B
Soil erosion	+A							-1									=	0
Income identity	+C				-C	-C	-/+C	-C		+C	-C		+/-C	+C		-1	=	F
Labor on-farm	+A								-1		-1		+A				=	0
Family labor supply									1	1		1					<=	B
Leisure demand												1				$-\beta$	>=	B
Oxen power	+A												-A				<=	0
Fertilizer	+A					-1											=	0
Seed use	+A			-A	-A												<=	0
Production	-A	+A	+A	+A													<=	0
Consumption			+A												+A	$-\beta$	>=	B
Cash income		+A								+A				+A			>=	B
Credit constraint						+A											<=	B
Rotations	+/-1																<=	0
Crop residue	-A					-1							+A				>=	0

[1] The C, A, B, F and β's represent, respectively, sets of objective function coefficients, input-output coefficients, available resource supplies or requirements, farm fixed costs, and the marginal propensity to consume estimated from a system of Engel equations. Allocation of labor and oxen power was specified over seven periods in a year.

Table 3.
Effect of productivity of conservation and inclusion of user costs of current soil erosion on resource use and conservation decisions of highland farm households in Ethiopia.

Issues considered	Basic model (without user costs)		All user costs accounted (r=0.54)		All user costs accounted (r=0.1)			All user costs accounted (r=0.05)		
	I&II[1]	III	I&II	III	I	II	III	I	II	III
Net income (Birr)	5580	5854	5387	5756	4778	4880	5461	4077	4533	5111
Teff (*kert*)[2]	5.91	5.66	5.84	5.64	5.67	5.74	5.57	5.03	5.59	5.48
Wheat	1.21	1.40	1.26	1.45	1.42	1.36	1.52	2.00	1.49	1.59
Barley	0.40	0.33	0.40	0.36	0.36	0.37	0.33	0.20	0.33	0.32
Field peas	0.07	0.13	0.23	0.14	0.15	0.29	0.16	0.33	0.32	0.19
Faba beans	0.54	0.57	0.28	0.55	0.51	0.27	0.44	0.55	0.26	0.43
Chick peas	1.14	0.73	1.17	0.56	0.69	0.78	0.50	0.71	0.80	0.47
Rough peas	0.37	0.37	0.37	0.35	0.36	0.36	0.33	0.37	0.35	0.33
Teff area upland	2.42	2.48	2.38	2.47	1.72	1.88	1.70	1.07	1.75	1.64
% upland conserved	0	86	0	87	0	45	100	39	100	100
Soil loss (t/ha)	38.1	21.0	37.9	21.0	36.0	26.3	18.1	26.9	17.9	18.1
Family labor supply (mandays)	215	207	219	213	240	267	230	319	289	252
Labor off- farm	64	54	72	55	91	57	57	58	58	58
Leisure	241	259	228	252	189	195	233	143	173	210
Hired labor	79	230	73	223	41	85	197	16	148	173
Teff consum.(kg)	837	865	818	855	760	770	827	692	736	844
Teff marketed surplus	944	950	891	956	920	933	917	701	904	870
Wheat consumption	344	359	333	354	300	305	337	260	286	318
Wheat marketed surplus	262	518	300	538	414	378	593	751	461	660

[1] The scenarios analyzed are:
I = Average anticipated yields with conservation are 20% less than conventional farming,
II = Average anticipated yields with conservation are equal to conventional farming, and
III = Average anticipated yields with conservation are 20% more than conventional farming.
r is the discount rate used in computing the present value of lost production.

[2] Sum of cultivated area of white, mixed and red varieties of teff.

Table 4.
The stationary equilibrium resulting from spreading the labor requirements for construction and maintenance of conservation structures over a 15 year period.

Productivity of conservation	Level of user cost[1]	Net Income (Birr)	Teff area (kert)	Wheat area (kert)	% upland conserved	Soil loss (t/ha)	Family labor supply	Hired labor	Leisure
Conservation	A	5580	5.91	1.21	0	38.1	215	79	241
is 20% less	B	5387	5.84	1.27	0	37.9	219	74	228
productive	C	5127	5.77	1.33	0	36.4	229	55	211
(I)	D	4779	5.67	1.42	12.6	34.2	244	41	188
	E	4188	5.86	1.25	78	21.4	282	27	150
Conservation	A	5580	5.91	1.21	0	38.1	215	79	241
is as good as	B	5425	5.86	1.25	72.7	22.6	233	86	230
conventional	C	5316	5.81	1.28	100	18.1	238	90	223
farming	D	5167	5.78	1.32	100	18.0	245	83	213
(II)	E	4841	5.69	1.41	100	18.0	264	52	192
Conservation	A	6213	5.74	1.35	100	18.2	185	139	282
is 20% more	B	6135	5.73	1.37	100	18.2	190	138	276
productive	C	6021	5.70	1.39	100	18.5	196	127	269
(III)	D	5862	5.67	1.43	100	18.8	206	112	259
	E	5462	5.57	1.52	100	18.6	231	82	233

[1] The scenarios analyzed are:
A = No user costs accounted,
B = All future productivity loss accounted (r=0.54),
C = All future productivity loss accounted (r=0.2),
D = All future productivity loss accounted (r=0.1), and
E = All future productivity loss accounted (r=0.05).

Table 5.
The effect of capital/credit constraints for fertilizer on short-term resource use, conservation, and consumption decisions of smallholders.

Yield effect of conservation	Level of user cost[1]	Net Income (Birr)	Teff area (kert)	Wheat area (kert)	Upland cereals (kert)	Lowland cereals (kert)	% upland conserved	Soil loss (t/ha)	Family Labor on-farm	Family Labor off-farm	Leisure
	A	5034	6.32	0.82	4.00	3.48	0	39	231	83	206
20% less productive (I)	B	4822	6.11	0.99	3.80	3.55	0	38.4	236	93	191
	C	4543	5.03	1.98	3.57	3.68	0	35.1	245	102	173
	D	4193	4.87	2.10	3.31	3.88	0	34.5	255	115	150
	E	3547	4.77	2.24	3.21	3.96	52	24.5	349	63	108
	F	4069	3.18	2.63	3.88	2.28	0	33.7	240	137	143
	G	3653	2.72	1.69	3.31	1.41	0	33.6	235	170	115
	H	3224	3.07	1.43	3.20	1.41	0	34.5	248	185	87
	A	5034	6.32	0.82	4.00	3.48	0	39	231	83	206
Same as conventional farming (II)	B	4714	6.10	0.99	3.94	3.55	16	33.5	265	71	184
	C	4572	5.97	1.20	3.78	3.61	21	32	282	63	175
	D	4316	5.48	1.52	3.47	3.97	41	26.7	303	58	159
	E	3963	4.86	2.10	3.37	3.81	100	17	327	58	135
	F-H[2]										
	A	5241	5.37	1.67	4.43	2.67	48	29	255	46	219
	B	5112	5.77	0.67	4.20	2.70	85	22.4	253	57	210
20% more productive (III)	C	4967	5.81	0.66	4.19	2.70	100	19.6	262	58	200
	D	4800	5.81	0.64	4.18	2.70	100	20	263	67	190
	E	4442	4.74	2.10	3.76	3.37	100	18	289	64	167
	F	4417	5.18	0.59	3.47	2.54	85	19.8	300	55	165
	G	4026	5.14	0.65	3.47	2.54	93	18.5	323	57	140
	H	3549	4.67	1.21	3.61	2.54	74	21.3	360	52	108

[1] The scenarios analyzed are:
A = No user costs accounted,
B = All future productivity loss accounted (r=0.54),
C = All future productivity loss accounted (r=0.20),
D = All future productivity loss accounted (r=0.10),
E = All future productivity loss accounted (r=0.05),
F = Same as B but fertilizer prices increase by 50%,
G = Same as B but fertilizer prices doubled, and
H = Same as B but fertilizer prices tripled.

[2] F-H in II are similar to F-H in I.

Annex 1.

Mathematical representation of the LP model.

$$\begin{aligned} Max \ & \sum_i \sum_l \sum_f \sum_k p_i Q_{ilfk} X_{ilfk} - \sum_i p_i Q_i^{bsd} - \sum_i p_i Q_i^{bc} - \sum_h p_h F_h - p_{af} FD^b \\ & - \sum_l P_l X_l - \sum_l \lambda_l SE_l + \sum_s (1-tc) w_s FL_s^{of} - \sum_s w_s HL_s - \sum_j cb_j A_j - \sum_j cr_j AR_j - \sum_j p_j AR_j^b \\ & + \sum_j p_j A_j^s + \sum_j p_j AN_j^s + \sum_z p_z AP_z^s - \sum_z p_z AP_z^{bc} - \phi OX^b - \psi OX^h - r_{gc} GC - r_{ic} IC \end{aligned} \tag{1}$$

Subject to:

Land resource use

$$\sum_i \sum_f \sum_k X_{ifkl} - X_l \leq L_l \tag{2}$$

$$X_l \leq X_l^m \tag{3}$$

Soil erosion

$$\sum_i \sum_f \sum_k SE_{ifkl} X_{ifkl} - SE_l = 0 \tag{4}$$

Fertilizer use

$$\sum_i \sum_l \sum_f \sum_k X_{ilfk} nr_{ilfkg} - \sum_h \eta_h^{cg} F_h \leq 0 \tag{5}$$

Seed use

$$\sum_l \sum_f \sum_k sd_{lfki} X_{lfki} - Q_i^{osd} - Q_i^{bsd} \leq 0 \tag{6}$$

Labor use

$$\sum_i \sum_l \sum_f \sum_k X_{ilfk} ld_{ilfks} + \sum_j A_j ld_{js} - FL_s - HL_s \leq 0 \tag{7}$$

$$LS_s^c - \delta_l Y \geq LS_s^{mcon} \tag{8}$$

$$FL_s + FL_s^{of} + LS_s^c \leq L_s \tag{9}$$

Ox (traction) power use

$$\sum_i \sum_l \sum_f \sum_k ox_{ilfks} X_{ilfk} - ox_s^{pd} OX^p \leq 0 \tag{10}$$

$$OX^p - OX^b - OX^h = OX^e \tag{11}$$

$$OX^h \leq OX^{hm} \tag{12}$$

Credit constraint

$$\sum_h p_h F_h - GC - IC \leq M \tag{13}$$

$$\begin{aligned} GC &\leq GC^p \\ IC &\leq IC^p \end{aligned} \tag{14}$$

Crop production balance

$$\sum_{l}\sum_{f}\sum_{k} Q_{lfki} X_{lfk} - Q_i^s - Q_i^{osd} - Q_i^c \geq 0 \tag{15}$$

Livestock production and replacement of breeding stock

$$A_j + A_j^s - A_j^b = A_j^e \tag{16}$$

$$\gamma_j A_j - AN_j^s - AN_j^c - AR_j \geq 0 \tag{17}$$

$$\left(mr_j + clr_j\right) A_j - AR_j - AR_j^b \leq 0 \tag{18}$$

$$A_j^s - clr_j A_j \leq 0 \tag{19}$$

Animal products balance

$$\sum_{j} AP_z A_j - \sum_{z} AP_z^c - \sum_{z} AP_z^s \geq 0 \tag{20}$$

Animal feed requirements

$$\sum_{i}\sum_{l}\sum_{f}\sum_{k} X_{ilfk}\, fd_{ilfk} - FD^b - \sum_{j} fr_j A_j \geq 0 \tag{21}$$

Subsistence consumption

$$\sum_{i} \theta_i^n Q_i^c + \sum_{i} \theta_i^n Q_i^{bc} + \sum_{j} \theta_j^n AN_j^c + \sum_{z} \theta_z^n AP_z^c + \sum_{z} \theta_z^n AP_z^{bc} \geq SR^n \tag{22}$$

$$\begin{aligned} Q_i^c + Q_i^{bc} - \delta_i Y &\geq Q_i^{mcon} \\ AP_z^c + AP_z^{bc} + AN_j^c - \delta_j Y &\geq AP_z^{mcon} \end{aligned} \tag{23}$$

$$(1) - Y = FC \tag{24}$$

Cash income

$$\begin{aligned} &\sum_{i} p_i Q_i^s + \sum_{s} (1 - tc) w_s FL_s^{of} + \sum_{j} p_j A_j^s + \sum_{j} p_j AN_j^s + \sum_{z} p_z AP_z^s \\ &- (1 + r_{gc})\, GC - (1 + r_{ic})\, IC_{ic} \geq \overline{C}_{inc} \end{aligned} \tag{25}$$

Where:
i = 1,..., I for crop production activities,
l = 1, 2 for the land types,
f = 1, 2, 3 for levels of fertilizer used,
h = 1, 2 for types of fertilizer used (DAP and Urea),
k = 1,..., K for types of conservation technologies,
j = 1,..., J for livestock production activities,
s = 1,..., S for different seasons of the year,
g = 1, 2 for plant nutrients in fertilizers (N and P),
n = 1, 2, 3 for dietary nutrients for humans (carbohydrate, fat, and protein),
z = 1,..., Z for animal products.

P_i = the market price of crop output i,
p_h = the price of fertilizer type h,
P_a = the price of animal feed, crop residues,
P_l = the price of renting in land type l,
λ_l = the marginal user cost of soil erosion on land type l (see note below),
tc = the cost of transportation to Debre Zeit town for off-farm labor supply,
w_s = the village market wage rate in season s,
cb_j = the cost of breeding livestock type j on the farm,
cr_j = the cost of rearing livestock type j on farm for replacement,
P_j = the market price of livestock type j,
P_z = the price of animal product z,
ψ = the cost of renting a pair of oxen for traction per year,
ϕ = the annualized cost of a pair of oxen bought during the year,
r_{gc} = the rate of interest on formal (government) credit,
r_{ic} = the rate of interest on informal (village) credit,
γ_j = the calving (lambing) rate of breeding females of livestock type j,
mr_j = the mortality rate of livestock type j,
clr_j = the culling rate for livestock type j
X_{ilfk} = the hectares (*ha*) of crop i grown on land type l using fertilizer level f and land management (conservation technology) k,
Q_{ilfk} = quantity (*kg/ha*) of crop i produced on land type l, using fertilizer level f and conservation technology k,
X_l = the areas (*ha*) of land type l rented in,
X_l^m = limit on land type l rented in,
L_l = the average area of "ownership" of land type l among surveyed farm households,
Q_i^{bsd} = the quantity of crop i bought for seed,
Q_i^{osd} = the amount of own seed of crop i used.
Q_i^{bc} = the quantity of crop i bought for household consumption,
Q_i^{s} = the quantity of crop i sold,
Q_i^{c} = the quantity of crop i consumed at home,
F_h = the quantity of fertilizer type h bought (kg),
FD^b = the quantity of animal feed bought (tons)
SE_{ifkl} = the amount of annual soil loss per *ha* of crop i grown on land type l with fertilizer level f and soil conservation technology k,
SE_l = the level of total annul soil loss on land type l,
nr_{ilfkg} = requirements of plant nutrient g (for N and P in *kg/ha*) for crop i grown on land type l with fertilizer level f and soil conservation technology k,
η_{hi}^{cg} = the composition of plant nutrient g per unit of fertilizer h,
SD_{ilfk} = the seed requirements per *ha* of crop i grown on land type l with fertilizer level f and soil conservation technology k,
ld_{ilfks} = the total mandays of labor required to produce one *ha* of crop i in season s grown on land type l with fertilizer level f and soil conservation technology k,
ld_{js} = the labor demand (mandays) per unit of animal j in season s,
FL_s = the number of mandays of family labor used on farm in season s,
HL_s = the total mandays of labor hired in season s,
FL_s^{of} = the total mandays of family labor supplied off-farm in season s,

FL_s^c = the total mandays of family labor time consumed as leisure in season s,

L_s = the total mandays of family labor available in season s,

ox_{ilfks} = the total amount of oxen pair days required in season *s* to produce one *ha* of crop *i* on land type *l* with fertilizer level *f* and soil conservation technology *k*,

ox_s^{pd} = the amount of oxen pair days available per pair of oxen in season s,

OX^p = the number of oxen pairs available on farm,

OX^b = the number of oxen pairs bought at the start of the production year,

OX^h = the number of oxen pairs hired in at the start of the year,

OX^e = the number of oxen pairs owned by the household at the start of the year,

GC = the amount of government fertilizer credit available (GC^p is limit on formal credit),

IC = the amount of informal credit available (IC^p is limit on informal credit),

M = own capital available for use in fertilizer purchase,

A_j^e = the number of breeding stock of livestock type *j* available on farm at the start of the year,

A_j^s = the number of breeding stock *j* sold (due to culling) in the year,

A_j^b = the total number of breeding stock *j* bought during the year,

AN_j^s = the number of livestock type *j* born on the farm and sold,

AR_j^c = the number of livestock *j* born on the farm and consumed at home (slaughtered),

AR_j = the number of livestock type *j* born and reared on farm,

AR_j^b = the number of livestock type *j* bought for rearing on farm,

AP_z = the amount of animal product *z* produced per unit of livestock type *j*,

AP_z^c = the amount of animal product z consumed at home,

AP_z^s = the amount of animal product z sold,

AP_z^{bc} = the amount of animal product z bought for consumption,

fd_{ilfk} = the quantity of crop residue dry matter (animal feed) produced per *ha* of crop *i* on land type *l* using fertilizer level *f* and soil conservation technology *k*,

FD^b = the quantity of animal feed (tons of dry matter) bought,

fr_j = the animal feed dry matter requirements per animal per year,

θ_i^n = the composition of nutrient *n* (protein, fat, carbohydrate) in crop *i* consumed,

θ_j^n = the composition of nutrient *n* (protein, fat, carbohydrate) in livestock type *j* slaughtered,

θ_z^n = the composition of nutrient *n* (protein, fat, carbohydrate) in animal product *z* consumed,

SR^n = the total annual nutritional requirement of the household for nutrient *n*,

Q_i^{mcon} = the level of subsistence consumption for crop product *i* (the constant term of the Engel consumption system for *i*),

AP_z^{mcon} = the level of subsistence consumption for animal product *z* (the constant term of the Engel consumption system for z),

LS_s^{mcon} = the number of mandays of subsistence consumption of leisure time (the constant term of the Engel consumption system for leisure),

FC = the farm fixed costs,

$\overline{C}_{inc}$ = the minimum cash income for the household (determined from the average cash income of surveyed farm households),

δ_i = the marginal propensity to consume crop type i,

δ_z = the marginal propensity to consume animal product z,

δ_l = the marginal propensity to consume leisure,

A note on estimation of the implicit cost of soil erosion.

The user cost of soil erosion, the perpetual discounted value of lost production from current soil erosion, is estimated from the production function for the major crop (teff) in the surveyed area. A production function for teff was estimated from the available time series experimental data conducted by the Soil Conservation Research Project. The following variables were used as regressors (other variables like fertilizer use were not included since the available data for fertilizer use was incomplete):

$Q_t = f(SODP, SLOPE, FPLOW, RFALL, TIME)$

where

Q_t is the yield of teff (ton ha^{-1}),

SODP is the soil depth in cm,

SLOPE is the slope gradient in per cent,

FPLOW the labor input in production as measured by the total frequency of plowing to planting,

RFALL is the average annual rainfall in mm,

TIME is the index of time for the range of empirical data used in the analysis,

The Translog production function gave the best fit for *f*. (For details on the estimated equation see text.) The marginal user cost of soil erosion was thus estimated for the two types of land as:

$$\lambda_l = \frac{p\left(10\dfrac{\partial f^l}{\partial SODP_l}\right)}{r}$$

Where,

p is the price per kg of teff,

r is the peasant's rate of discount,

$\partial f^l / \partial SODP_l$ is the marginal product of 1 cm of soil depth (approx. equal to 100 ton of soil loss per ha^{-1}) evaluated at the average level of soil depth and slope in land type l, and at the average values of the other variables. The marginal product was multiplied by 10 to arrive at the implicit cost of 1 ton of soil loss in kg of teff.

Analysis of Economic Incentives for Soil Conservation: The Case of Highland Peasant Households in Ethiopia

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Abstract

Degradation of land continues to pose a significant threat to future food production potential in many developing economies. Various approaches, mainly based on mandatory policies, have been unsuccessfully tried in the past to encourage adoption of erosion-control practices by peasant households. High transactions costs and negative distributional impacts on the welfare of the poor limit the usefulness standards and taxes for soil and water conservation. One innovative approach is the use of interlinked contracts in which positive incentives are employed to induce peasants initiate land conservation. This study analyses the social efficiency of such incentives and the factors that influence the peasants' ability to install erosion-control techniques on erodible lands using farm household data from the Ethiopian highlands. Moreover, the role of price policies to stimulate land conservation at the farm-level is also investigated.

Key words: Land degradation, policy intervention, economic incentives, peasant agriculture.

1. Introduction

The problem of land degradation and loss of food production potential in poor rural economies with fast growing populations has received increasing attention in recent years (Southgate, 1988; Anderson and Thampapilai, 1990; Scherr and Yadav, 1996). Soil and water conservation (SWC) has, therefore, become an important area of public intervention. In many less developed countries (LDCs), various SWC programs have unsuccessfully tried to mitigate the land degradation problem. Appropriate institutions and policy incentives that efficiently internalize Pareto-relevant land degradation externalities are urgently needed in many countries that suffer from deterioration of their resource base.

In a world without market failures[1], farming practices and conservation investments undertaken by individual farmers also maximize the discounted value of social net returns in land use. Thus, government intervention, on efficiency grounds, is not needed. The necessary conditions for the social efficiency of private land use require that markets are perfectly competitive and that prices of all resources relevant for the well-being of all individuals reflect their social scarcity values. However, rural economies in LDCs are often far from being competitive, and face pervasive impediments (high transactions costs and imperfect information) and weak enabling conditions (incomplete property rights) (Hoff *et al.,* 1993). Covariate risk also contributes to pervasiveness of market imperfections. Although the underlying factors behind excessive land degradation in rural economies of LDCs await detailed investigation, the divergence between private and social paths of soil use may be attributed to imperfect information, high transactions costs, imperfect insurance and capital markets, incomplete property rights, and misguided government policies.[2]

The interlinkages between poverty, population growth, and environmental degradation further complicate and reinforce the potential impact of market imperfections. Smallholders may, therefore, base their land use and investment decisions on distorted price signals and the resulting allocations may fail to mimic the socially optimal path (McConnell, 1983; Shiferaw, 1996). Soil conservation investments that would increase social efficiency may, therefore, fail to be undertaken by individual users, and excessive degradation of land may ensue as is reported in several case studies. However, from the efficiency perspective, the existence of market failures per se is not a sufficient condition for government intervention into market processes. The efficient level of land conservation that equates marginal social benefits and costs of abating degradation can result in a soil erosion level either lower or higher than the natural rate of regeneration. Thus, the mere existence of the land degradation externality does not necessitate policy intervention. The likelihood of a policy failure (inefficient intervention) and a net social welfare loss further strengthens this point. Hence, an economic efficiency justification for augmenting the "invisible hand" mechanism with a "visible hand" approach requires that (a) the existence of market failures is demonstrated, and (b) evaluation of social costs and benefits of intervention indicate a net gain to society. Intervention is, therefore, justified when the net social benefit of conservation is shown to be positive.

The incentives approach, based on voluntary behavior of resource users, is also likely to be more successful than a coercive or regulatory approach to resource conservation (Chisholm, 1987; Panayotou, 1993). The non-point nature of the soil erosion externality, and the high cost of monitoring individual levels of input use make first-best policies difficult to implement. Thus, in countries like the United States, soil conservation policy emphasizes an approach based on cooperative behavior in response to positive incentives (Reichelderfer and Kramer, 1993). In LDCs, regulatory standards and user charges on degrading inputs or soil loss are even more difficult to implement due to weak regulatory capability, scarcity of information, high transactions costs, and adverse distributional impacts on poor smallholders.

The purpose of this paper is to evaluate the role of various policy incentives for soil conservation and examine the rationale for public intervention into the market mechanism using data from the Ethiopian highlands. Emphasis is given to positive incentives, like cross-compliance and cost-sharing policies, which are also expected to provide positive distributional benefits to poor farmers. Moreover, the role of output pricing policies in relation to the erosivity of the crops grown is also examined. The rest of the paper is organized as follows. Section 2 presents the conceptual framework. Section 3 provides description of the Ethiopian case study and methods. Section 4 presents and discusses the results. A summary and policy implications are given in the final section.

2.0 Conceptual Framework

2.1 The economic incentives approach to soil conservation

Once the existence of a socially excessive level of land degradation is known, governments may resort to various policy instruments for mitigating or internalizing the externalities. Some policy instruments specify quantity standards on the level of emission of the externality that cannot be exceeded by generators of that externality. This type of command-and-control regulations entail inflexible limits or technological requirements and stipulate a range of penalties for non-compliance. In contrast, the economic incentives approach utilizes market-based instruments designed to modify the behavior of the generators of the externality through their effect on the prices of resource inputs used in economic activities.

The choice of policy instruments, however, depends on (a) efficiency of use of scarce information, (b) contracting, monitoring, and enforcement costs, (c) distributional effects, and (d) political preferences. An ideal instrument may be the one satisfying the goals of efficiency, equity, and simplicity (Chisholm, 1987) as well as political feasibility. Accordingly, due to the lack of information on land-specific optimal levels of soil erosion, and prohibitive costs of monitoring the production activities of millions of scattered smallholders and enforcement of standards, the regulatory approach has very limited relevance for soil conservation. A mix of regulatory and incentives approaches may, however, be useful in some cases. For example, past soil conservation programs in Ethiopia used a mix of coercive and incentives approaches. In some food deficit areas, soil conservation structures were installed on lands perceived to be erodible through food-for-work (FFW) incentives. Peasants were forced to keep the structures although maintenance was mainly done through FFW incentives. Enforcement of these type of policies was possible mainly due to strong local state power since peasant associations were entrusted with overseeing compliance. However, when the FFW incentive stopped and coercion was relaxed since the late 1980s, many peasants selectively or totally dismantled structures (Shiferaw and Holden, 1996).

The economic incentives approach to soil conservation may use a range of instruments. Provision of secure land rights, price support and reduction of export taxes to less erosive crops, resource pricing (e.g. irrigation water), input taxes (subsidies), and credit subsidies are some examples. Secure land rights may extend the planning horizon and vest with the owner the benefits of investments in land improvement and conservation and serve as institutional instruments that act as economic incentives (Panayotou, 1993). Besides, macropolicies, like devaluation of overvalued exchange rates and interest rate adjustments, can be used. The effect of a general increase or decrease in commodity prices on soil and water conservation is unclear (Barbier, 1991; LaFrance, 1992; Pagiola, 1996). It has been argued that depressing agricultural prices may reduce profitability of farming and dampen land-improving or soil-conserving investments, whilst increasing commodity prices through its effect of raising farm returns may encourage cultivation of marginal lands (Southgate, 1988). It may also be argued that in the presence of a suitable land use policy, and where rights to land are clearly defined, increased profitability of farming through higher prices may make conservation more attractive to the farmer. The impact of price changes on land management also depends whether the conserving input has beneficial or adverse impacts on yields (Shiferaw, 1996). Changes in relative prices, however, can have predictable impacts depending on the crops and inputs that are promoted or discouraged and the farmers' ability to respond to such price changes. A rise in the profitability of less erosive crops relative to more erosive crops can, for example, be expected to encourage soil-conserving land use and cropping patterns, and conversely (Southgate, 1988; Barbier, 1991; Panayotou, 1993).

The Pigouvian approach to internalizing externalities calls for taxes on degrading inputs and subsidies on conserving inputs in proportion to the marginal external damages or benefits resulting from the use of each input (Baumol and Oates, 1988). In the first best case, this requires information on the level of use of each type of input on each land type. Thus, governments prefer taxing the use of degrading inputs or subsidizing conserving inputs. When farmers have sufficient economic incentives to adopt soil-conserving practices on profitability grounds, the best policy is not provision of subsidies, rather removal of constraints that deter adoption. When significant off-site effects of soil erosion exist, conservation subsidies may be justified although on-site effects may be minimal.

However, designing and running a suitable subsidy scheme presents several incentive and targeting problems (Chisholm, 1987; Lutz *et al.*, 1994): (a) production subsidies for inputs with significant external effects may artificially boost profitability of activities using these inputs and encourage resource depletion and degradation, (b) conservation subsidies may create perverse incentives to farmers to increase rates of soil erosion to qualify for subsidies or encourage planting on marginal lands made profitable through subsidies, and (c) subsidies as incentives may modify farmer behavior only as long as they continue to be paid. This implies that subsidies may have to be paid for maintenance as well. Therefore, a subsidy scheme should be designed carefully, and often entails a heavy strain on the economies of poor countries, especially when no external assistance is made available.

2.2 Cross-compliance for targeting economic incentives

One mechanism for targeting economic incentives for conservation is based on interlinked compliance strategies that employ a mix of regulations and incentives approaches based on voluntary behavior and positive economic incentives (Holden and Shanmugaratnam, 1995). Cross-compliance (interlinkage) means that conservation requirements are linked to access for a vital input (e.g. irrigation water) or access to certain farm program benefits is made contingent upon installing erosion control practices on erodible lands. Cross-compliance policies for resource conservation under peasant farming may offer the following advantages:

(i) Whilst direct subsidies for productive inputs may distort price signals and erode the incentive to economize and conserve scarce resources, subsidies linked to conservation can help mitigate the land degradation externality. Removal of input subsidies through adjustment programs and currency devaluation may also cause soaring prices for ameliorative inputs (like fertilizer) that may encourage soil mining and diminish the income of the poor. However, production subsidies linked to conservation can have positive effects on both the environment and the welfare of the poor. Subsidies for productive inputs linked to conservation can enable poor households comply with conservation requirements without adverse impacts on their welfare, especially when the latter do not provide quick benefits. The increased production through such subsidies may boost national food security that may also benefit the urban poor and rural net buyers through lower prices resulting from increased surplus. In food deficit countries like Ethiopia, increased production can also contribute to self-sufficiency and reduce food imports. If improvements in efficiency, environmental quality, and equity can be achieved, such policies represent a win-win-win strategy.[3]

(ii)Where asymmetric information and transactions costs lead to market failures, despite differing distributional impacts, interlinked contracts may result in more efficient outcomes than could be achieved through isolated transactions (Bose, 1993; Hoff and Stiglitz, 1993). When the regulating agency lacks full information on plot-specific erosion levels, on-site and off-site effects, and profitability of conservation technologies, interlinking of different markets symbolize efficient institutional innovations for targeting positive incentives to achieve environmental targets through effective use of scarce information.

In what follows, we analyze the effect and efficiency of various economic incentives for soil conservation based on our case study in the Ethiopian highlands.

3.0 Case Study in Ethiopia

3.1 Agriculture and land degradation: past and present policies

By all accounts, agriculture is the predominant sector of the economy. The sector is primarily dependent on smallholder farming. Smallholders cultivating fragmented micro-holdings produce more than 90% of the annual agricultural output. Despite its pivotal role, the performance of the sectors has remained largely unsatisfactory. Food self-sufficiency remains to be an unattained objective. Between 1979/80 and 1993/94 food production grew by 0.5% per year while population grew by 3%, implying a per capita food production decline of 2.5% (Zegeye and Habtewold, 1995). Another serious concern coupled with the stagnation of the sector has been the degradation of the resource base mainly due to soil erosion (FAO, 1986). The problem of degradation of the soil stock and loss of production potential is severe in the highlands that harbor 88% and 75% of the human and livestock populations, and constitute 95% of the cultivated lands. FAO (1986) estimates that 50% of the highlands are significantly eroded; of this, 25% are seriously eroded, while 4% have been estimated to have reached "a point of no return". Hence, soil erosion induced productivity decline is estimated to average 2.2% per annum from that of the 1985 level. Estimated annual rates of soil erosion on croplands at national level average 42 t/ha (Hurni, 1993). In a country with a fast growing population vulnerable to frequent famines that claimed the lives of millions of people, the rapid loss of food production potential is a concern not only for future generations but also for the present generation of Ethiopians.

The stagnation of the agricultural sector and degradation of the resource base can be attributed to several interrelated factors: misguided policies and neglect of the sector, technological stagnation, weak institutional support, insecure land rights, high population pressure, drought, political instability, and frequent wars (Shiferaw, 1994). Consistent with the general neglect of the agricultural sector in development theory, policy support to the sector prior to 1974 was very poor. Some of the reforms that followed the 1974 revolution, like "land to the tiller", were later liquidated by misguided policies and ardent socialist orientation. Until the late 1980s, agricultural input and output marketing remained under state monopoly while pan-territorial prices were fixed below the free market level. Policy support for credit, input distribution, output marketing, and extension was mainly targeted towards cooperatives and state farms that jointly accounted for only 10% of the agricultural produce. Excessive surplus extraction and discriminatory policies discouraged private smallholder production and land-improving investments.

As a result of such misguided economic polices, the 1975 land reform policy also failed to provide impetus to boost production and enhance sustainable land use. Although the reform policy enabled many landless peasants to gain access to land, the state ownership of land and the insecurity of usufruct rights hindered consummating the full potential of the reform. Land still remains under state control while peasants only possess insecure use rights that can be terminated by the government without compensation. Land markets are outlawed and land does not have a legal asset value. Moreover, rural infrastructure is poorly developed, agricultural research is rudimentary, and new technologies for production or conservation are largely unavailable. Recent data indicate that improved seeds, irrigation, and fertilizer are used only on 0.71%, 0.97%, and 25% of the cultivated fields (CSA, 1996). Information on erosion-productivity relations or control measures is scanty and unavailable to peasants. Formal credit is available only for short-term loans for fertilizer, while long-term loans for investment in land or livestock are lacking.

The data for this study comes from a detailed survey by the author of a stratified sample of 120 farm households in Ada district of the central highlands of Ethiopia in 1994/95. The production system in Ada is typical of the mixed crop-livestock system in the highlands. Although soil erosion is a problem mainly on erodible uplands, introduced erosion control structures or terraces are not used. Less effective traditional practices like drainage furrows, water ways, and cut-off drains are used together with crop rotations where peasants perceive the threat of soil erosion. Informal short-term land contracts are common although such practices lack legal basis. Formal credit was available for fertilizer at a rate of 12%, but the informal rates reach as high as 100%. Estimated real rates of discount (discrete time rate) among the surveyed households average 54% (Holden *et al.*, 1996).

3.2 Analytical methods

Land use and conservation decisions of farm households are conditioned by their dual engagement in production and consumption which will in turn be shaped by the policy environment, institutional arrangements (market structures, land tenure, extension, credit, infrastructure), population pressure, asset endowments, household characteristics, access to new technologies, and off-farm employment opportunities (Reardon and Vosti, 1992; Shiferaw and Holden, 1997). When production and investment decisions are conditioned by consumption preferences and household characteristics, a farm household approach is needed for analysis of land use and investment decisions of smallholders.

This study develops a nonseparable farm household model for analysis of the role of economic incentives for soil-conserving land use. The full description of the basic structure of the model is given in Shiferaw and Holden (1997) and in Annex 1 (Paper III). The linear programming (LP) model identified a production plan that maximized annual net returns defined as current net returns less the present value of future income loss caused by land productivity decline due to soil erosion (on-site user costs) subject to various farm-level resource supply and behavioral constraints. The condensed structure of the LP model is given in Table 1. The model includes crop production activities on two land types (upland and lowland) with three levels of fertilizer use, two technological options (improved and traditional varieties), and two land management options (with and without conservation) and livestock production, sale and consumption activities. Labor use activities (leisure, on-farm, off-farm, and hiring options) were defined seasonally, and activities for crop sale and consumption were included. The constraints included limits on "owned" and rented land, labor (including leisure), oxen power, subsistence needs, animal feed requirements, restrictions on credit, crop rotations, and cash income.

Soil erosion levels for each production activity on two land types and two management options were estimated using the modified Universal Soil Loss Equation (USLE) adapted for Ethiopian conditions (Hurni, 1985). Actual measurements also provided values for the slope length and slope gradient factors of the USLE. The effect of soil erosion on productivity was estimated econometrically based on time series data[4]. The marginal user costs of soil (discounted perpetual productivity losses per ton of eroded soil) were assessed on levels of gross erosion from the two land types. The optimized value thus maximized the returns to farming and non-farming activities less the user cost of current soil erosion. Activity budgets and resource supplies were specified for a representative household reflecting the average of 120 households surveyed.

The cross-compliance policies analyzed include differing levels of input subsidies (for fertilizer, improved seeds, and a mix of fertilizer and improved seeds) offered only when upland cereals are grown on land treated with conservation. When the incentive (linked to conservation) makes production on conserved land profitable, the peasant uses subsidized inputs to an optimal level and adopts conservation structures while traditional practices and unsubsidized inputs may continue to be used on the remaining land. The cost-sharing policies considered were differing subsidies per unit of labor used for installing conservation structures (soil bunds) on erodible slopes. The incentives were given at varying levels per unit of labor used in conservation activities. The cost-sharing is provided for subsidizing the initial high costs of installing conservation structures. The overall cost share to the peasant may, however, be zero if the initial incentive is larger than the total construction and maintenance costs. The cost-shares are thus computed as a share of the total discounted cost of construction and maintenance of structures. Since soil conservation is assumed to be undertaken between January and May, before the planting season that starts in June, labor costs are computed using the shadow value of labor during this period.

The subsidies are specified for cases where conservation does not provide immediate economic benefits to the peasant (when short-term crop yields with conservation are the same or less than without conservation). However, subsidies may still be necessary when the yield-improving effect of conservation is not sufficient to cover the full cost of conservation even if yields may initially be higher with conservation. Since surveyed farm households indicated that available techniques, for various reasons, tend to depress immediate yields or do not show appreciable changes at best, our focus is on the evaluation of incentives that may be employed to increase the adoption of the existing techniques.

A benefit-cost analysis of cross-compliance and cost-sharing policies was done by computing the net present value of soil productivity loss prevented over the lifetime of conservation practices when the incentive is provided less the flow of all real social costs of conservation as given in (1).

$$\sum_{t=1}^{T}\Big(\lambda(E_t^i - E_t^{wi}) - \left[\theta(1-\gamma)(I_t + M_t) + S_t + A_t\right]\Big)(1+\rho)^{-t+1} \qquad (1)$$

Where, E^i and E^{wi} are, respectively, soil erosion levels with and without the incentive, I is the initial labor requirement for installing conservation structures ($I_{t>1} = 0$), M_t is the annual labor requirement for maintenance of structures ($M_{t=1} = 0$), S_t is the cost of the subsidy in year t, A_t is annual administrative costs (assumed 10% of the subsidy cost), λ is the marginal user cost (the shadow value) of soil erosion, θ is the shadow value of family labor, and γ is the cost-sharing covered by the incentive (for the cost-sharing policy only). The incentive required in subsequent years ($S_{t>1}$) to induce the peasant maintain structures once built through the starting incentive ($S_{t=1}$) was estimated by computing the income level that would equalize the flow of benefits with conservation to that without conservation as given by:

$$\sum_{t>1}^{t^{+}-1}\left(\pi_t^c - \pi_t^{nc}\right)(1+r)^{-t} \qquad (2)$$

Where π_t^c and π_t^{nc} are farm profits with and without conservation, respectively. When production costs are similar in the two regimes, this can be represented as:

$$\sum_{t>1}^{t^{+}-1}\left(p(Y_t^c - Y_t^{nc}) - C_t^c\right)(1+r)^{-t} \qquad (3)$$

Where p is the output price, Y is the yield per ha, $C=\theta M_t$ is the shadow value of conservation labor, and r is the peasant's rate of discount. The incentive is needed until the discounted net benefits of switching to the soil conserving practice are positive in year t^{+}. Using (3), the level of the incentive required after the first year was directly estimated to be Birr 430 ha^{-1} of conserved land. The benefit-cost analysis was done at differing social rates of discount ($\rho = 0.05, 0.1, 0.2$) for $T=15$ years. Thus, the incentive is considered to improve social welfare when (1) is positive or the benefit-cost ratio is sufficiently greater than 1. Finally, the effect of changing the relative prices of erosive and non-erosive crops on land use and conservation decisions was examined through a 20% decrease (increase) of the price of an erosive crop (teff) or less erosive crops (pulses), respectively.

4.0 Results and Discussion

4.1 Effect of cross-compliance policies

The effect of cross-compliance policies for fertilizer and improved seed inputs on land use and conservation investment are presented in Table 2. When conservation reduces immediate benefits, no conservation of erodible lands occurs until about 50% of the (1993/94) price of fertilizer is covered through the subsidy. Even at 50% subsidy, only some 20% of upland cereals (17% of the uplands) are grown on conserved land. The increase in the level of the subsidy to 75% and 90%, respectively, raises adoption of conservation to 45% and 62% of the upland area[5]. The benefit-cost ratios (BCR) for 50% to 90% fertilizer subsidies show that, considering the on-site effects of soil erosion alone over the 15 year period, provision of the incentive will not increase net social benefits unless the social rate of discount is close to 5%. At the 10% rate, the incentive is also unlikely to be socially profitable, even if one assumes that structures may form terraces and have a longer lifetime (BCR = 1.07 for the 90% fert. subsidy). Only an increase in the marginal user cost of soil (by 50% from 11 Birr/t at $\rho = 0.1$) or a lowering of the social rate of discount could make the incentive a Pareto improvement. Since switching into a conserving practice lowers immediate income, it requires more than 90% subsidy before the incentive could have a significant impact on the smallholder's land use and investment behavior. The soil loss declined progressively from 35.6 t/ha without the subsidy to 25.7 t/ha with 90% subsidy. Since the subsidy for fertilizer relaxes the credit constraint and allows the peasant to use recommended levels of the input, the returns to the incentive increase with the level of the subsidy. But, more conservation also brings higher subsidy costs from the second year and hence makes profitability difficult to attain. Thus, at $\rho=0.1$, it requires more than a 90% subsidy before the incentive becomes socially attractive.

When yields are 20% less with conservation, an improved seed (assumed to be 30% more productive than the traditional cultivars) subsidy for cereals is, however, socially profitable even at $\rho=0.1$. When technological change allows a 30% rise in productivity, a shift into the soil-conserving practice allows a 10% increase in yields over traditional cultivars grown without conservation thereby allowing adoption of conservation practices without severe impacts on meeting subsistence needs. Moreover, compared to the fertilizer subsidy, the seed subsidy has a lower average cost per area conserved. Thus, although it requires up to 90% subsidy (the price of improved seed considered 30% higher than traditional cultivars) to induce some conservation, at $\rho \leq 0.1$, both 90% and 100% seed subsides are socially efficient. In this case, a subsidy for improved seeds linked with conservation that sufficiently counteracts the yield-depressing effects of structures and induces conservation at lower cost is likely to be socially more attractive than a high cost fertilizer subsidy. However, even with the 100% seed subsidy, the level of conservation achieved in the short-term is very low (12% of the upland area). Soil loss only decreased from 38.7 t/ha without the seed subsidy to 36.2 t/ha with the 100% subsidy.

When conservation leaves yields unchanged, even a 10% fertilizer subsidy activates some 24% of upland cereals to be grown with conservation. An increase in the level of the fertilizer subsidy to 25%, brings all the upland cereals (84% of the upland area) into conservation farming. A further increase in the level of the fertilizer subsidy to 50% encourages slightly more conservation and cropping of cereals on uplands (86% conserved). Further increase in the level of the subsidy does not spur much conservation as land hiring and rotational constraints begin to be binding. Besides, the higher demand for conservation labor and the parallel increase in opportunity cost of labor as the level of the subsidy increases, reduce the marginal conservation effect of the incentive. However, the 10% to 50% improved seed subsidies are socially efficient. Hence, a policy that would bring all cereals grown on erodible slopes into conservation farming is also socially efficient. Soil erosion progressively declined from 35.6 t/ha without the incentive to 20 t/ha with the 50% fertilizer subsidy.

With a yield-neutral conservation technology, the improved seed subsidy will also have a comparable level of social efficiency as the fertilizer subsidy. Again this is related to the lower cost of the seed subsidy per unit of land conserved. A policy that plans to transform all cereals on uplands to conservation farming is also socially efficient at $\rho \leq 0.1$. However, the BCR increase initially, reach a maximum between 10% and 50% levels, and start to fall thereafter. As in the case of the fertilizer subsidy, the fall in BCR after the 25% level is related to the differences in the erosivity of the crops (and hence user costs) that compel conservation on the most erosive crop (teff) first, and a rise in the opportunity cost of labor in farming with the increase in the level of the subsidy. This is observed in the form of a larger decrease in the soil erosion level from 10% to 25% subsidy compared to higher levels of the subsidy. Similarly, the decrease in soil erosion per unit area conserved is larger for the subsidy below the 25% level than those above this level. This implies that although the area under conservation increases with the subsidy, after some level, the marginal change in soil erosion falls as less erosive crops come to be grown on treated lands. The incentive decreased soil erosion successively from 37.3 t/ha without the incentive to 22.2 t/ha with the 75% seed subsidy.

The effect of a mix of fertilizer and seed subsidies is presented in Table 3. For the case of yield-depressing conservation, a 50% seed subsidy was combined with differing levels of fertilizer subsidies. Although uncombined 50% seed subsidy brought no conservation, adding a fertilizer subsidy of 25%, 50%, and 75%, respectively, raised the upland cereal area conserved to 13.5%, 99%, and 100%. The first two combinations are economically efficient at $\rho \leq 0.1$, but the 50-50 scheme was only marginally so. If soil conservation is a preferred social goal, a policy that enables all cereals on uplands to be grown with conservation is socially efficient at $\rho \leq 0.1$. The rise in the profitability of farming following the increase in the subsidy, raises the opportunity cost of labor used for conservation. This, combined with the differing erosivity of crops, introduces decreasing returns to the subsidy. If the subsidy increases above the 75% level (not shown), the peasant will continue to grow all cereals on uplands with conservation, but the upland cereal area will be reduced as the high subsidy allows intensive cropping on lowlands using high levels of fertilizer (recommended fertilizer use and associated yields are higher on lowlands). Until the lowland area is binding, this permits a reduction in the cost of conservation and increased use of fertilizer and new seeds on the less-erodible soils thereby reducing the level of soil erosion further. In this case, the BCR follows a U-shape. The incentive progressively reduced soil erosion from 38.7 t/ha without the incentive to 20 t/ha with the 50-100 seed-fertilizer subsidy.

For the case of yield-neutral conservation, a 10% fertilizer subsidy was combined with differing levels of seed subsidies. Table 2 shows that a 10% improved seed subsidy led to the adoption of conservation technology on 12% of uplands. Adding a 10% fertilizer subsidy raises adoption to about 14% of the upland area operated. Similarly, mixing a 10% fertilizer subsidy with 25% and 50% seed subsidies raises adoption, respectively, from 39% and 66% to 67% and 80% of the cultivated upland area. Thus, a 50% improved seed subsidy is almost equivalent to a mix of a 10% fertilizer subsidy with 25% seed subsidy. This implies that, depending on the availability of the incentive and anticipated impacts on government budgets, the fertilizer and seed incentives can be combined in different proportions without a loss in their effectiveness to induce conservation. At $\rho \leq 0.1$, the mix of seed and fertilizer subsidies is also socially efficient. Conservation can be extended to 80% of the uplands without loss of efficiency. The BCR of the incentive seems to be increasing first and decreasing later mainly due to the differences in the erosivity of cereals and a rise in the shadow value of labor. The most efficient incentive level is to be reached between the 10-10 and 50-10 mix of seed-fertilizer subsidies. The incentive system reduced soil erosion successively from 37.3 t/ha without the subsidies to 23 t/ha at the 50-10 seed-fertilizer subsidy.

4.2 Effect of cost-sharing and payments to conservation labor

Analytical results for the cost-sharing incentive system are also given in Table 3. When conservation is yield-depressing, none of the uplands would be conserved if the initial payment is less than 120% (4 Birr/laborday (B/L)) of the total discounted cost of construction and maintenance of bunds. Thus, the cost-sharing policy turns out to be an incentive payment scheme since the technology will not be adopted unless the incentive covers more than the entire investment cost. Increases in the incentive payment to 220% and 280% (7 and 9 B/L) raised adoption of the soil-conserving technology to 17% and 30% of the upland area. Soil erosion decreased progressively from 38 t/ha without the incentive to 32 t/ha with the 280% incentive payment. Although the area conserved increases with the incentive payment, the scheme is inefficient and efficiency falls as the public "cost-sharing" increases.

With a yield-neutral conservation, even a 20% (1 B/L) cost-sharing could propel some conservation. If the cost-sharing is raised to about 60% (3 B/L), all uplands would come under conservation farming. Under the current situation where improved seeds are unavailable for all upland crops and fertilizer is used only on a few crops, the cost-sharing policy may, therefore, be an effective means of achieving a wider adoption of conservation structures. All levels of the labor subsidy are efficient at $\rho \leq 0.1$. Soil erosion declined successively from 38 t/ha without the subsidy to about 18 t/ha with a 60% cost-sharing. Like the case of other incentives, there are both increasing and decreasing returns to the incentive scheme. The most efficient level of cost-sharing seems to be achieved between 20% and 60%.

4.3 Effect of pricing policies

Taxing the price of an erosive crop (teff): The incentive effect of depressing the price of an erosive but a major cash and staple crop (teff) by 20%, relative to other crops, is given in Table 4. In response to the relative price change, smallholders adjust their land use and cropping patterns. The area under teff is more than halved while the area under wheat is more than doubled, and the area of pulses increases by about 60%. Household income falls by up to 12% as a result. When the peasant begins to incorporate the user costs of current soil erosion into decision making, teff ceases to be grown on erodible lands. Even when user costs are unaccounted for (in the basic model), soil loss decreases by 12% (5 t/ha) although bunds have not been installed on the uplands. Similarly, soil erosion decreases by 16% without adoption of bunds when user costs are accounted at high rates of discount ($r = 0.54$). As more weight is given to future productivity loss, reduction in teff area alone is insufficient to mitigate erosion and adoption of conservation structures becomes necessary. Despite the lower rates of conservation, the change in cropping patterns allows reduction of soil erosion to levels below what was attained with higher rates of conservation before the price change. For example, while it requires 45% upland conservation without the price policy to reduce soil erosion to 26 t/ha, a 39% conservation with the price policy reduces erosion to 25 t/ha.

Due to the fall in income, the consumption of leisure decreased by up to 23%, while the consumption of teff waned by up to 14%. Since wheat is not a substitute for teff and due to the fall in income, the consumption of wheat also decreases by up to 10%. The price policy also prompts peasants to be only self-sufficient in teff. Thus, wheat largely substitutes for the decline in the marketed output of teff. Although this partial analysis does not reveal the general equilibrium effects, the policy is likely to have substantial impacts on the marketing of teff and wheat. The decrease in marketed surplus of teff may have an eventual effect of driving up teff prices. The increased supply of wheat may also depress its own price. In our model, prices are exogenous and such second-round effects can not be traced. Future research should investigate such effects in a multi-market or general equilibrium framework.

Supporting the price of less-erosive crops (pulses): Table 5 presents, the incentive effect of supporting the relative price of less-erosive crops (horse beans, field peas, lentils, chick peas, and rough peas) by 20%. These pulses together account for about 20% of the cropped area. Despite the very low yields, peasants do not use fertilizer on these crops. Pulses are often used for replenishing soil nutrients and they precede cereals in the rotation cycle. They are also mainly produced for own consumption. Thus, the responsiveness to the prices of these crops is likely to be limited. The results also indicate that, unlike the case of the teff price-tax policy, the relative increase in the profitability of pulses does not decrease the area under teff to bring a significant reduction in soil erosion. Teff planted on erodible slopes did not also show a significant decline. The area under wheat also remains about half of that under an equivalent tax on the price of teff. The pulse area also increased only marginally or remained the same. As a result, the desired effect of the price policy to stimulate soil-conserving land use and cropping pattern did not succeed. Hence, the soil erosion level remained comparable to that before the price change. Due to limited impacts on the cropping pattern, inclusion of user costs also required comparable levels of upland conservation to mitigate soil erosion. Since household income showed only a slight increase, the effect on consumption was limited. Marketed surplus of teff declined by up to 20% in the basic model, but this effect disappears when user costs are considered. The overall outcome of the pulse price-support policy does not differ much from the case without the policy. The low relative prices of pulses and their low current yields limit the effectiveness of the policy[6]. Under the current low productivity of pulses, a much larger pulse price-support is required before significant changes in cropping patterns occur to have any notable effect on soil erosion. Thus, the pulse price-support policy did not bring a comparable change in behavior as the teff price-tax policy.

5.0 Summary and Policy Implications

The problem of land degradation and productivity decline in countries with fast growing populations that are also suffering from poverty and malnutrition has become an important area for government intervention. From the viewpoint of economic efficiency alone, the mere existence of land degradation does not, however, necessitate public intervention to mitigate the problem. An economic rationale for public intervention to conserve the soil stock requires, first, that the existence of market failures leading to a socially excessive land degradation are verified, and second, intervention to reduce the degradation problem should bring a social welfare improvement. In the context of peasant agriculture, divergence between private and social efficiency of land use may occur due to: incomplete property rights, imperfect/incomplete rural input/output markets, imperfect information, transactions costs, and policy failures. Market failures when they exist, may impair market signals received by smallholders and encourage socially sub-optimal land use and investment patterns. This study analyzes some incentives that can be employed to justify public intervention to mitigate the on-site soil erosion externality using farm household data from Ethiopia, where a severe problem of land degradation and policies that discourage sustainable land use have been documented.

Where rural poverty is widespread, cross-compliance policies that link production incentives with soil conservation can provide opportunities for countering productivity declines from soil erosion without adverse impacts on the welfare of the poor and the marketed surplus of food. Such policies may, therefore, represent improvements in efficiency, equity, and environmental quality. However, when conservation technologies significantly reduce immediate household income, as is reported by land users in our case study, fertilizer subsidies linked to conservation do not improve social efficiency unless the social rate of discount is less than 5%. Seed subsidies and a mix of seed and fertilizer subsidies were, however, more efficient since they enable sizable reductions in erosion damage at low cost. If the social rate of discount is as high as 20%, such economic incentives also become socially inefficient. When structures leave immediate benefits unchanged, the cross-compliance policies for fertilizer, and a mix of seed and fertilizer inputs were able to reduce erosion-induced productivity loss efficiently. The efficiency of these incentives also drastically declines as the social rate of discount rises above 10%, and become inefficient at the 20% rate. The level of erosion abated with the incentives also declines after most erosive crops have been grown on treated lands, indicating a point of maximum efficiency in the level of the incentive. The cross-compliance approach is also found to be more effective to counter the soil erosion externality than unlinked input subsidies. When unlinked input subsidies are provided, the enhanced profitability of farming obliterates the need to invest in conserving the soil stock and thus conservation disappears as the subsidy increases (see Appendix 4.1).

Furthermore, at rates of discount larger than 10%, the cost-sharing or incentive payment policy was not efficient when conservation is yield-depressing. At the 10% level, cost-sharing, however, enabled complete conservation of erodible uplands efficiently when conservation is yield-neutral in the short-term. Utilizing the peasant's own labor for conservation during periods of low farm activity through incentives, like food-for-work programs that also provide employment opportunities for the poor, may therefore be an effective approach for soil conservation. If such incentives are made available through external assistance, the loss of production potential of agricultural land and expansion into marginal lands and clearing of forest cover can be mitigated without imposing a heavy strain on meager government budgets of poor countries.

The efficiency of the incentives depends on the user cost of soil erosion, the social rate of discount, and the life time and productivity effects of conservation structures. An increase in the user cost, a decrease in the rate of discount, and an increase in the life of bunds improve the efficiency of the incentives. The user costs depend on the productivity impact of soil erosion, output prices, and the social rate of discount. A decrease in soil depth and technical change raise the productivity impact of soil erosion. Increase in prices and a decrease in the discount rates also raise the user costs. If user costs increase by 50%, from 11 to 16.5 Birr/t of soil erosion, all the incentives analyzed will be socially efficient at the 10% rate of discount. Moreover, taxing the most erosive crop (teff) is more effective in abating soil erosion than supporting the prices of less erosive crops (pulses). The limited success of the latter approach was mainly due to low prices and productivity of pulses. Since general equilibrium effects of price policies were not captured, results need to be interpreted cautiously until such effects are investigated in future work. Moreover, implementation of policies linked to grain prices may prove to be difficult, especially when taxing is involved. One approach that needs to be investigated in detail is linking the tax/subsidy to the operated area of erosive and non-erosive crops on erodible lands.

End Notes

[1] Despite its common usage in economics, the market failure concept is subject to controversies (e.g. see Papandreou, 1994). Some also ascribe the instances of market failures (e.g. externalities, public goods, monopolies, etc.) as the fundamental causes. We define market failures in the broadest sense to mean the failure of the market system to achieve social Pareto efficiency in the allocation of resources. Market failure thus implies the existence of Pareto-improving exchanges or profitable production decisions that can make some group better off without making any other group worse off. Given that individuals wish to make themselves better off, the inefficiency (Pareto-relevant externalities) may persist due to: (a) incomplete property rights, (b) imperfect/incomplete markets, (c) imperfect-asymmetric information, (d) high transaction costs, and (e) bargaining problems. Policy instruments attempt to improve efficiency by mitigating or eliminating market failures. If the costs of intervention exceed benefits based on current knowledge, the market failure does not as such have relevance on efficiency grounds. In such a case, the situation may be "constrained Pareto efficient". Thus, strictly speaking, a market failure may be defined as a situation where known efficient instruments exist to mitigate or eliminate the inefficiency.

[2] Kirby and Blyth (1987) provide a good treatment of sources of market failures in relation to land degradation in industrial agriculture (in Australia).

[3] When population control policies are in place, positive incentives linked to conservation may be instrumental for breaking the poverty-environment trap. If such subsidies can be offered temporarily to encourage conservation-based rural development, they also represent win-win-win options. Fast growing population and other constraints may, however, undermine the efficiency of such incentives.

[4] The values used in the modified USLE and the estimated erosion rates by crop and land type, and the translog production function used for estimation of user cots are given in Paper III. Also see Shiferaw and Holden (1997).

[5] The corresponding ratio of the upland area conserved is different from the cereal area conserved since fertilizer is only used for cereals (teff, wheat, and barley) and at present local improved varieties of pulses are unavailable.

[6] The 1993/94 average yields (kg/*kert*) of teff and pulses were 280 and 200, while average prices (Birr/kg) were 2.38 and 1.60, respectively. *Kert* is approximately 0.3 hectare. Average prices at selected sites in the highlands are given in Appendix 4.4. Average crop yields in Debre Zeit are given in Appendix 4.5.

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Table 1. An aggregated structure of the nonseparable farm household model[1].

	Produce crops	Sell crops	Consume crops	Use own seed	Buy Seed	Buy fertilizer / animal feed	Hire in/out land	Soil erosion	Family labor on farm	Family labor off-farm	Labor hiring	Leisure	Keep breeding stock and oxen	Sell livestock	Consume livestock	Income	Relation	RHS
Objective	+C				-C	-C	-/+C	-C		+C	-C		+/-C	+C				MAX
Land	1						-/+1										<=	B
Soil erosion	+A							-1									=	0
Income identity	+C				-C	-C	-/+C	-C		+C	-C		+/-C	+C		-1	=	F
Labor on-farm	+A								-1		-1		+A				=	0
Family labor supply									1	1		1					<=	B
Leisure demand												1				$-\beta$	>=	B
Oxen power	+A												-A				<=	0
Fertilizer	+A					-1											=	0
Seed use	+A			-A	-A												<=	0
Production	-A	+A	+A	+A													<=	0
Consumption			+A												+A	$-\beta$	>=	B
Cash income		+A								+A				+A			>=	B
Credit constraint						+A											<=	B
Rotations	+/-1																<=	0
Crop residue	-A					-1							+A				>=	0

[1] The C, A, B, F and β's represent, respectively, sets of objective function coefficients, input-output coefficients, available resource supplies or requirements, farm fixed costs, and the marginal propensity to consume estimated from a system of Engel equations. Allocation of labor and oxen power was specified over seven periods in a year.

Table 2.
Incentive effects of a cross-compliance policy (fertilizer and improved seed subsidies linked to conservation).

	Conservation 20% less productive					Conservation equally productive						
	Fertilizer subsidy (%)			Seed subsidy (%)		Fertilizer subsidy (%)			Seed subsidy (%)			
	50	75	90	90	100	10	25	50	10	25	50	75
Net Income (Birr)	4408	4590	4718	5278	5289	4432	4598	4937	5285	5309	5436	5628
Hired labor (*Manday*)	93	97	127	71	71	94	161	181	72	69	164	212
Leisure	164	176	185	221	221	166	176	199	222	223	231	244
Area conserved (*kert*)	0.80	2.15	2.91	0.53	0.55	0.96	3.89	4.07	0.57	1.76	3.33	4.14
Upland conserved (%)	16.5	45	62	11.6	11.9	19.5	84	85.8	11.9	38.8	66.0	83.8
Upland cereal area conserved (%)	20.0	52.8	71.6	13.3	13.7	23.6	100	100	14.4	49.9	79.0	100.0
Soil loss (t/ha)	33.8	29.3	25.7	36.4	36.2	31.5	20.9	19.8	35.4	29.4	25.5	22.2
Total damage prevented[1] *(Birr)*	***172***	***583***	***914***	***211***	***227***	***382***	***1352***	***1460***	***177***	***726***	***1085***	***1393***
Cost of the subsidy[2]	130	449	622	90	95	7	77	196.1	3	23	81	159
Installation and maintenance costs	92	246	332	61	63	182	743	776	110	336	635	790
Cost of conservation[3]	***235***	***741***	***1017***	***160***	***167***	***190***	***828***	***991***	***113***	***361***	***724***	***965***
Average costs	293	343	350	299	304	199	212	243	196	205	217	233
Benefit/Cost[4]												
$\rho = 0.05$	1.77	1.92	2.19	3.19	3.28	4.36	3.58	3.30	3.41	4.39	3.30	3.21
$\rho = 0.1$	**0.73**	**0.79**	**0.90**	**1.32**	**1.36**	**2.01**	**1.63**	**1.47**	**1.57**	**2.01**	**1.50**	**1.44**
$\rho = 0.2$	0.27	0.29	0.33	0.49	0.50	0.86	0.69	0.60	0.68	0.86	0.63	0.59

[1] The sum of the present value of annual yield losses prevented due to conservation over the life time of conservation structures (15 years) discounted over perpetuity.

[2] In addition to the first year investment incentive, this includes the subsidy (430 Birr/ha) for subsequent years that would equalize the net benefits with conservation to that without conservation. The latter is an estimate of the additional subsidy required to persuade the peasant to maintain bunds computed according to (3). Under the estimated rates of erosion in the area, when conservation is 20% less productive, it takes about 11 years for yields under the conserving and degrading practices to equalize. When conservation is yield-neutral, no such subsidies are needed after the first year.

[3] The cost of conservation includes the total costs of the subsidy, administrative costs (assumed to be 10% of the subsidy cost), own construction and annual maintenance costs over 15 years.

[4] Total damages prevented/Cost of conservation. All other calculated values are for $\rho = 0.1$.

Table 3.
Incentive effects of a cross-compliance policy (a combination of improved seed and fertilizer subsidies linked to conservation) and cost-sharing policy for conservation labor.

	Conservation 20% less productive (I)						Conservation equally productive (II)					
	Seed and fertilizer subsidy (%)			Labor subsidy (Birr/manday)			Seed and fertilizer subsidy (%)			Labor subsidy (Birr/ manday)		
	50-25	50-50	50-75	4	7	9	10-10	25-10	50-10	1	2	3
Net Income (*Birr*)	5274	5350	5645	5253	5285	5338	5306	5382	5557	5260	5277	5356
Hired labor (*Manday*)	71	196	216	70	91	106	69	165	193	70	145	221
Leisure	221	225	245	219	221	225	223	227	239	219	220	226
Area conserved (*kert*)	0.54	4.11	4.34	0.28	0.84	1.47	0.63	3.34	4.11	0.58	2.64	4. 58
% upland conserved	11.7	84.3	86.7	6	17.2	30.3	13.7	66.6	80.4	12.7	57.7	100
Upland cereal area conserved (%)	13.5	99.2	100	6.9	20.7	36.2	17.1	79.2	100	14.7	69.7	113
Soil loss (t/ha)	37.2	21.7	21.1	37	35	32.5	35.3	25.3	23	35.2	24.7	18.2
Total damages prevented[1] (Birr)	***206***	***1570***	***1614***	***82***	***296***	***565***	***181***	***1103***	***1316***	***249***	***1211***	***1814***
Cost of subsidy[2]	91	717	948	75	315	660	8	70	138	21	191	497
Installation and maintenance costs[5]	103	783	827	0	0	0	145	763	940	90	312	375
Conservation costs[3]	***204***	***1572***	***1870***	***83***	***346***	***726***	***154***	***837***	***1091***	***113***	***522***	***922***
Average costs	376	382	430	295	414	494	243	251	266	194	198	235
Benefit/Costs[4]												
$\rho = 0.05$	2.39	2.35	2.06	2.57	2.23	2.03	2.55	2.88	2.66	4.77	5.03	4.28
$\rho = 0.1$	**1.01**	**1.00**	**0.86**	**0.99**	**0.86**	**0.78**	**1.17**	**1.32**	**1.21**	**2.21**	**2.32**	**1.97**
$\rho = 0.2$	0.38	0.38	0.32	0.33	0.29	0.26	0.50	0.56	0.50	0.95	1.00	0.84

[1], [2], [3], [4] See the description given under Table 2.

[5] When immediate yields with conservation are 20% less, all installation and maintenance costs are covered by the cost-sharing and thus the peasant's costs are nil. The peasant receives Birr 9, 116, and 311, respectively, under each level of the labor subsidy above the total social cost of labor used for construction and maintenance of bunds. This is, however, part of the social cost of conservation.

Table 4.

Effect of taxing the price of teff (an erosive crop) by 20% on resource use and conservation decisions of highland farm households in Ethiopia (as % of the before price change).

Issues considered	Basic model (without user costs)	All user costs accounted ($r = 0.54$)	All user costs accounted ($r = 0.1$)		All user costs accounted ($r = 0.05$)	
	I&II	I & II	I	II	I	II
Net income	89.2	89.1	88.7	88.3	88	88.3
Teff[2] (*kert*)	53.3	42.9	44.2	43.6	68.4	53.7
Wheat	266.9	291.0	254.6	265.2	153.5	221.5
Barley	45.0	43.2	60.1	59.6	85.0	60.6
Pulses	167.9	176.7	203.4	77.5	128.1	153.8
Teff area upland	26.9	0.0	0.0	0.0	0.0	0.0
% upland conserved	*0.0 (0)*	*0.0 (0)*	*0.0 (0)*	*86.7 (39)*	*56.4 (22)*	*100.0 (100)*
Soil loss (t/ha)	*88.5 (33.7)*	*84.1 (31.8)*	*87.8 (31.6)*	*96.5 (25.4)*	*104.1 (28)*	*87.7 (15.7)*
Family labor supply (manday)	103.3	103.2	100.0	114.2	93.4	110.7
Labor off- farm	150.0	144.4	139.6	98.2	191.4	106.9
Leisure	83.4	83.3	81.0	81.0	76.9	79.8
Hired labor	75.9	64.4	75.6	38.8	0.0	64.2
Teff consum. (kg)	86.0	93.2	93.2	93.0	92.9	93.1
Teff market. surplus(kg)	19.3	0.0	0.0	0.0	46.9	22.8
Wheat consumption	90.1	90.1	90.0	89.5	89.6	89.5
Wheat marketed surplus	501.5	513.0	372.9	406.6	174.2	305.4

[1] The scenarios analyzed are:

I = Immediate yields with conservation are 20% less than conventional farming,

II = Immediate yields with conservation are equal to conventional farming, and

r is the peasant's real rate of discount used in computing the present value of lost production.

The numbers in parentheses refer to actual values after the price change. Values of all variables are given in Appendix 4.2.

[2] Sum of cultivated area of white, mixed and red varieties of teff. All area units are given in the local unit *kert*, approximately 0.3 hectare (ha).

Table 5.

Effect of supporting the price of pulses (less erosive crops) by 20% on resource use and conservation decisions of highland farm households in Ethiopia (as % of that before price change).[1]

Issues considered	Basic model (without user costs)	All user costs accounted ($r = 0.54$)	Six year user costs accounted ($r = 0.1$)		All user costs accounted ($r = 0.1$)	
	I & II	I & II	I	II	I	II
Net Income (Birr)	102.1	102.2	101.7	101.6	102.0	101.7
Teff (*kert*)	92.6	92.7	100.1	98.9	97.6	100.4
Wheat	133.1	131.9	98.7	103.5	105.0	98.7
Barley	77.5	74.9	102.0	99.0	95.0	100.0
Pulses	113.2	119.5	100.2	109.0	100.5	100.6
Teff area upland	88.4	88.3	107.2	105.0	88.8	101.1
% upland conserved[2]	*0.0(0)*	*0.00(0)*	*0.00(0)*	*119(53)*	*94.9(37)*	*100.0(100)*
Soil loss (t/ha)	*98.2(37.4)*	*98.6(37.4)*	*100.6(36.2)*	*95.4(25)*	*99.3(26.7)*	*100.6(18)*
Family labor supply (mandays)	98.1	98.6	98.3	98.1	98.4	98.3
Labor off- farm	93.8	93.1	98.9	100.0	98.3	100.0
Leisure	102.9	103.5	102.6	102.6	103.5	102.3
Hired labor	105.1	105.5	114.6	125.9	106.3	101.4
Teff consumption (kg)	101.4	101.6	101.1	101.0	101.2	101.1
Teff market. surplus (kg)	81.4	84.4	97.8	95.3	94.2	99.9
Wheat consumption	102.0	102.1	101.3	101.6	101.9	101.4
Wheat marketed surplus	175.2	164.7	96.6	104.8	105.6	96.7

[1] For additional descriptions, see the note under Table 4.

[2] Actual analytical results for all variables are given in Appendix 4.3.

Appendix 4.1

The effect of cross-compliance policies (incentives linked to conservation) on soil conservation decisions as compared to incentives unlinked to conservation.

Subsidies (%)	Unlinked subsidy		Linked subsidy	
	Upland conserved (%)	Soil loss (t/ha)	Upland conserved(%)	Soil loss (t/ha)
Fertilizer subsidy - I				
0	0.0	35.6	0.0	35.6
25	0.0	39.4	0.0	35.6
50	0.0	37.9	16.6	33.8
75	0.0	38.0	45.0	29.3
90	0.0	37.2	62.0	25.7
Fertilizer subsidy-II				
0	0.0	35.6	0.0	35.6
10	0.0	38.7	19.5	31.5
25	0.0	39.3	84.0	20.9
50	0.0	38.0	85.8	19.8
Seed subsidy- I				
0	0.0	38.7	0.0	38.7
90	0.0	41.5	11.6	36.4
100	0.0	41.5	11.9	36.2
Seed subsidy - II				
0	6.5	37.3	6.5	37.3
10	5.5	36.6	11.9	35.4
25	3.4	36.6	38.8	29.4
50	0.0	39.5	66.0	25.5
75	0.0	42.4	83.8	22.2
Seed-Fertilizer subsidy -I				
50-25	0.0	39.6	11.7	36.5
50-50	0.0	36.0	84.3	21.7
50-75	0.0	36.1	86.7	21.1
Seed-Fertilizer subsidy -II				
10-10	2.8	36.7	13.7	35.3
25-10	0.5	37.4	66.6	25.3
50-10	0.0	42.5	80.4	23.0

Note: Anticipated yields with conservation are 20% less than without conservation = I
Anticipated yields with conservation are the same as that without conservation = II

Appendix 4.2

The effect of taxing the price of an erosive crop (teff) by 20% on resource use and conservation decisions of highland farmers at Deberzet, Ethiopia.

	Without user costs (I&II) Before	Without user costs (I&II) After	% change	All user costs at r=0.54 (I&II) Before	All user costs at r=0.54 (I&II) After	% change	All user costs at r=0.1 (I) Before	All user costs at r=0.1 (I) After	% change	All user costs at r=0.1 (II) Before	All user costs at r=0.1 (II) After	% change	All user costs at r=0.05 (I) Before	All user costs at r=0.05 (I) After	% change	All user costs at r=0.05 (II) Before	All user costs at r=0.05 (II) After	% change
Net income (Birr)	5580	4977	89.2	5387	4800	89.1	4778	4237	88.7	4880	4309	88.3	4077	3580	88	4533	4003	88.3
Teff (kert)2	5.91	3.15	53.3	5.84	2.51	42.89	5.67	2.505	44.2	5.74	2.51	43.6	5.03	3.44	68.4	5.59	3	53.7
Wheat	1.21	3.23	266.9	1.26	3.67	291.03	1.42	3.62	254.59	1.36	3.61	265.2	2	3.07	153.5	1.49	3.3	221.5
Barley	0.4	0.18	45.0	0.4	0.17	43.17	0.36	0.22	60.12	0.37	0.22	59.6	0.2	0.17	85.0	0.33	0.2	60.6
Pulses	2.12	3.56	167.9	2.05	3.62	176.72	1.71	3.48	203.42	1.7	1.32	77.5	1.96	2.51	128.1	1.73	2.66	153.8
Teff area upland	2.42	0.65	26.9	2.38	0.00	0.00	1.72	0.00	0.00	1.88	0.00	0.0	1.07	0	0.0	1.75	0	0.0
% upland conserved	0	0	0.0	0	0.00	0.00	0	0.00	0.00	45	39.03	86.7	39	22	56.4	100	100	100.0
Soil loss (t/ha)	38.1	33.7	88.5	37.9	31.87	84.10	36	31.63	87.87	26.3	25.37	96.5	26.9	28	104.1	17.9	15.7	87.7
Fam. lab. supply (manc	215	222	103.3	219	226	103.2	240	240	100.0	267	305	114.2	319	298	93.4	289	320	110.7
Labor off- farm	64	96	150.0	72	104	144.4	91	127	139.6	57	56	98.2	58	111	191.4	58	62	106.9
Leisure	241	201	83.4	228	190	83.3	189	153	81.0	195	158	81.0	143	110	76.9	173	138	79.8
Hired labor	79	60	75.9	73	47	64.4	41	31	75.6	85	33	38.8	16	0	0.0	148	95	64.2
Teff consum.(kg)	837	720	86.0	818	762	93.2	760	708	93.2	770	716	93.0	692	643	92.9	736	685	93.1
Teff marketed surplus	944	182	19.3	891	0	0.0	920	0	0.0	933	0	0.0	701	329	46.9	904	206	22.8
Wheat consumption	344	310	90.1	333	300	90.1	300	270	90.0	305	273	89.5	260	233	89.6	286	256	89.5
Wheat marketed surplu	262	1314	501.5	300	1539	513.0	414	1544	372.9	378	1537	406.6	751	1308	174.2	461	1408	305.4

Appendix 4.3

The effect of supporting the price of less erosive crops (pulses) by 20% on resource use and conservation decisions of highland farmers at Deberzet, Ethiopia.

	Without user costs (I&II) Before	Without user costs (I&II) After	% change	All user costs at r=0.54 (I&II) Before	All user costs at r=0.54 (I&II) After	% change	All user costs at r=0.1 (I) Before	All user costs at r=0.1 (I) After	% change	All user costs at r=0.1 (II) Before	All user costs at r=0.1 (II) After	% change	All user costs at r=0.05 (I) Before	All user costs at r=0.05 (I) After	% change	All user costs at r=0.05 (II) Before	All user costs at r=0.05 (II) After	% change
Net income (Birr)	5580	5697	102.1	5387	5508	102.2	4778	4857	101.7	4880	4956	101.6	4077	4159	102	4533	4610	101.7
Teff (kert)2	5.91	5.47	92.6	5.84	5.41	92.65	5.67	5.678	100.1	5.74	5.68	98.9	5.03	4.91	97.6	5.59	5.61	100.4
Wheat	1.21	1.61	133.1	1.26	1.66	131.96	1.42	1.40	98.74	1.36	1.41	103.5	2	2.1	105.0	1.49	1.47	98.7
Barley	0.4	0.31	77.5	0.4	0.30	74.98	0.36	0.37	102.06	0.37	0.37	99.0	0.2	0.19	95.0	0.33	0.33	100.0
Pulses	2.12	2.4	113.2	2.05	2.45	119.49	1.71	1.71	100.16	1.7	1.85	109.0	1.96	1.97	100.5	1.73	1.74	100.6
Teff area upland	2.42	2.14	88.4	2.38	2.10	88.27	1.72	1.84	107.15	1.88	1.97	105.0	1.07	0.95	88.8	1.75	1.77	101.1
% upland conserved	0	0	0.0	0	0.00	0.00	0	0.00	0.00	45	53.49	118.9	39	37	94.9	100	100	100.0
Soil loss (t/ha)	38.1	37.4	98.2	37.9	37.4	98.6	36.0	36.2	100.6	26.3	25.1	95.4	26.9	26.7	99.3	17.9	18.0	100.6
Fam. lab. supply (manc	215	211	98.1	219	216	98.6	240	236	98.3	267	262	98.1	319	314	98.4	289	284	98.3
Labor off- farm	64	60	93.8	72	67	93.1	91	90	98.9	57	57	100.0	58	57	98.3	58	58	100.0
Leisure	241	248	102.9	228	236	103.5	189	194	102.6	195	200	102.6	143	148	103.5	173	177	102.3
Hired labor	79	83	105.1	73	77	105.5	41	47	114.6	85	107	125.9	16	17	106.3	148	150	101.4
Teff consum.(kg)	837	849	101.4	818	831	101.6	760	768	101.1	770	778	101.0	692	700	101.2	736	744	101.1
Teff marketed surplus	944	768	81.4	891	752	84.4	920	900	97.8	933	889	95.3	701	660	94.2	904	903	99.9
Wheat consumption	344	351	102.0	333	340	102.1	300	304	101.3	305	310	101.6	260	265	101.9	286	290	101.4
Wheat marketed surplu	262	459	175.2	300	494	164.7	414	400	96.6	378	396	104.8	751	793	105.6	461	446	96.7

Appendix 4.4

Average prices of agricultural products in the Ethiopian highlands (Debre Zeit, Andit Tid and Anjeni) in the 1993/94 agricultural year.

	Crop Prices (Birr/100 kg)				Livestock Prices (Birr/live animal)		
Crop type	Debre Zeit	Andit Tid	Anjeni	Animal type	Debre Zeit	Andit Tid	Anjeni
White teff	270	237	150	Milking cow	800	650	950
Mixed teff	240	190	136	Non-milking cow	475	400	750
Red teff	205	172	121	Ox	1000	900	750
Wheat	167	140	148	Heifer	325	275	350
Barley	85	117	123	Bull	450	250	550
Maize	147	-	110	Calf	175	70	225
Faba beans	112	125	120	Ewe	95	50	110
Field peas	270	180	190	Ram	80	80	110
Chick peas	150	-	138	Lamb	60	45	55
Rough peas	107	-	87	Doe	75	50	85
Lentils	160	180	202	Buck	60	80	75
Linseed	-	175	179	Kid	40	40	30
Niger seed	-	-	198	Horse	500	600	400
Rape seed	-	-	149	Mule	1800	850	800
Sorghum	-	137	-	Donkey	400	275	180
Finger millet	-	-	142				

Appendix 4.5

Average yields and fertilizer use reported by 120 surveyed farmers at Debre Zeit (1993/94).

	Yield (kg/kert)		Fertilizer Urea use (kg/kert)		Fertilizer DAP use (kg/kert)	
Crop	Uplands	Lowlands	Uplands	Lowlands	Uplands	Lowlands
White teff	283.3	275.7	13.7	15.8	29.7	31.4
Mixed teff	251.5	253.7	14.6	16.6	27.5	33.9
Red teff	283.2	258.7	15.2	12.7	28.7	26.7
Durum wheat	244.4	242.6	13.1	13.7	13.9	24.9
Bread wheat	181.6	179.0	12.2	10.0	21.1	18.0
Other wheat	204.2	150.0	20.8	10.6	18.3	13.8
Barley	352.4	-	1.3	-	2.8	-
Rough pea	-	233.0				
Field pea	145.0	-				
Faba bean	217.8	-				
Chick peas	-	241.3				
Lentils	141.6	-				

Cropping Calendar at Ada District, East Shewa

Cropping Activity	January	February	March	April	May	June	July	August	September	October	November	December
Teff	threshing harvesting		second plowing first plowing		3rd plowing	4-5 plowing	planting	weeding			harvesting	Threshing
Wheat	threshing		2-3 plowing				Planting	Weeding			Harvesting	Threshing
Barley						2-3 plowing	Planting	Weeding		Harvesting	Threshing	
Maize			2-3 plowing			planting	weeding			Harvesting decobbing		
Field peas						1-2 plowing planting	weeding			Harvesting and threshing		
Faba beans						1-2 plowing planting	weeding			Harvesting and threshing		
Rough peas								1-2 plowing	Planting	weeding		Harvesting & threshing
Lentils						1-2 plowing planting	weeding			Harvesting & threshing		
Chick peas								1-2 plowing	Planting	weeding		Harvesting & threshing

Cropping Calendar at Andit Tid area (North Showa).

Cropping Activity	January	February	March	April	May	June	July	August	September	October	November	December
Barley Meher	1st plowing thre	shing	Plo (2nd p	wing lowing)	Planti	ng		wee	ding	harves	ting	1st plowing
Barley Belg	plant (cont'd)	ing				Harv Thres	esting hing		Plo	wing Threshing (delayed)	(2-3)	planting
Wheat	Plow Harvesting	ing (2-3) Threshing					Planting		weeding			First plowing
Field peas (Meher)	Threshing (cont'd)					Plowing & planting				Harve	sting	Threshing
Field peas (Belg)	plant (cont'd)	ing				Harves	ting Threshing		plow	ing (1-	2)	Planting
Faba beans	Threshing (cont'd)					1-2 plow ing planting			Weeding		Harvesting	Threshing
Linseed	Plowing (1-2) Thre	shing		Planting							Harv	esting
Lentil (Meher)						1-2 plowing planting				Harvesting Thr	eshing	
Lentil (Belg)	Plow plan '(cont'd	ing ting)				Harves	ting Threshing		plowi '(first	ng)		planting

The Major Questionnaire Used for Household-Farm Survey, 1993/94[1]

I Household Background

Household (HH) Number____________________

Date:	Ethnic Group:
Interviewer:	Religion:
PA/Village:	Type of House:

	Name	Relation to head of HH	Sex	Age	Married to	Skill (weaver, carpenter,black smith, etc)	Depend on HH supply of food	Where lived last year	How long in this village	Months on farm last year	Days out of work last year	Level of education	Occu-pation
1													
2													
3													
4													
5													
6													
7													
8													
9													

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[1] Although this formed the basic structure, some questions were adjusted to fit local conditions in the three sites in the highlands.

* Relation to household head: wife, child, child in-law, grand child, brother, sister, hired labor, relative, other.

* Level of education: Can't read or write = 0, Read & write (*meserete timihirt*) = 1, Read & write (*priest*) = 1.5, Formal education in years.

* Occupation: Dependent = 0, Student = 1, Watch after animals (*Eregna*) = 2, Housewife = 3, female servant = 4, Hired labourer (*Arash*) = 5, family labor full time worker = 6, PA official = 7, others (specify)________________ = 8.

Production objectives and inventory of food reserve and cash capital shortly before the 1993/94 and 1994/95 crop harvest.

Asset	Mainly for markets	Mainly for Consumption	Only for markets	Only for consum.	Minimize risk	Replenish soil fertility	Other Objectives (state)	Last year December stock	This year December stock
W.Teff									
M.Teff									
R. Teff									
Wheat									
Barley									
Nug									
Flax									
F. peas									
Beans									
Other crops (specify)									
Money in cash									
Cows									
oxen									
Sheep									
Goats									
Other animals									
....									

II. Expenditure on Agricultural Inputs.

Item	Quantity used	Own	Purc hased	Market	Unit Price (Birr)	Total Expen diture	Source of money	Amount on Govt credit	Inform al credit	Amou nt paid on interest
Fertilizer Urea (kg)										
Fertilizer DAP (kg)										
Seed W.teff (kg)										
Seed M.teff (kg)										
Seed R.teff (kg)										
Seed Wheat (kg)										
Seed barley (kg)										
Seed C.peas (kg)										
Seed F.peas (kg)										
Seed H.beans (kg)										
Seed lentils (kg)										
Seed maize (kg)										
Seed Niger seed										
Seed Flax (Linseed)										
Herbicides										
Pesticides										
Agric. implements										
Oxen										
Animal feed										
Animal salt										

* Agricultural implements include: hoe, spades, *maresha, wegel, kenber, mofer, digir, miran, jiraf,* etc.

* Market: Service Coop = 1, Village market = 2, Local market = 3, Other market (far from local market) = 4.

* Source of money: Own source =1, Govt credit=2, Informal credit (3a-3f), Item directly borrowed (*madaberiya woyim zer bebidir*) =4, Offered free = 5.

Informal Credit (3a - 3f):

3a) Church
3b) Edir
3c) Ekub
3d) Relative/Friend
3e) Village lender
3f) Others (specify)____________________

III Household Consumption Expenditure

No	Item	Amount	Per (period)	Market	Price	Unit	Total per year	Total Expenditure	Origin of money	
1	**a) Crop Staples** Teff									
2	Wheat									
3	Barley									
4	Maize									
5	Millet									
6	F.peas,(etc)									
9	Lentils									
10	Flax (*Telba*)									
11	Niger seed (*Nug*)									
12	Pepper (*Berberie*)									
1	**b)Animal Staples** Butter									
2	Beef (*kircha*)									
3	Sheep									
4	Goat									
5	Chicken									
6	Eggs									
1	**c)Manufactured Goods, etc** Clothing									
2	Soap (w. powder)									
3	Shoes									
4	Matches									
5	Kerosine									
6	Cooking oil									
7	Sugar									
8	Coffee									
10	Tea									
11	Salt									
12	Corrugated iron									
13	Umbrella									
14	Cooking Utensils									
15	Battery cell (box)									
15	Furniture									

Cooking utensils include: pots (*Biret or shecla dist), Biretmitad, Mitad, Ensira*, ladle (*chilfa*), glasses, kettle (*mankorkoria*), etc.

Furniture: Tables, chairs, beds, mattresses, etc. Other comments same as **II** above.

IV Crop Production Activities

Crop	Cultivated Area (local unit)	Soil Conservation (area & type)	Rented land area	Total output	Fertilized Area	Amount of fertilizer used	Payment for hiring labor	Where lived	Type of oxen rental	Payment for renting oxen	Where lived	Pay. for renting land	Where lived	Net HH Production
White Teff UL														
White Teff LL														
Mixed Teff UL														
Mixed Teff LL														
Red Teff UL														
Red Teff LL														
Wheat UL														
Wheat LL														
Barley Meher														
Barley Belg														
Maize														
F.peas														
H.beans														
C.peas														
Lentils														
Flax (Linseed)														
Nug														

* Area Cultivated: Total area cultivated in the cropping year.

* Soil Conservation (area & type): Area of conserved cultivated land in local units followed by a comma and TR if traditional, LB if level bund, GB if graded bund, LF if level Fanja-ju, GF if graded Fanja-ju, GS if grass strips, or NO if no soil conservation practiced. (eg.5 kert, TR).

* Amount of fertilizer used: Phosphorous (DAP) and nitrogen (Urea) fertilizer are often used in a known proportion of 2:1.

* Type of oxen rental: 0 if no oxen rented, 1 if arrangement is Minda (farmers with uneven number of oxen holdings rent a single ox to pay a certain share of the total produce), 2 if arrangement is Mekenajo (farmers with uneven number of oxen agree for pairing which allows cultivation on alternate days on each other's plot), 3 if arrangement is Minda but 2 or more oxen are rented, 4 if farmer obtained oxen free of charge.

* Crops are grown on either Upland (UL) if cultivated land lies on well-drained hill-side red soils - more susceptible to erosion - or Lowland (LL) if cultivated land lies at the less drained black soils of the valley bottoms - less susceptible to erosion.

1. Area of Land under fallow ____________ and years under fallow ____________
2. What is the reason for fallowing
   a) Lack of sufficient oxen for cultivation ____________
   b) Shortage of family labor and inability to hire labor ____________
   c) Shortage of family labor and absence of a labor market____________
   d) To let the land regain its fertility ____________ e) Other reasons (specify) ____________.
3. Area of own permanent grazing land ____________
4. Total area of land under the farmers holding
   Cultivated land ____________ Rented out land____________
   Fallow land ____________ Grazing land____________
   Total holding size ____________

5. Rank constraints to production of each crop according to importance (1 as most important).

Crops	Land scarcity	Soil erosion	Lack of credit	Low crop prices	Pests and diseases	Shortage of labor	High fertilizer prices	Delays in fertilizer supply	Hail storms	Drought	Frost
Teff											
Wheat											
Barley											
....											
....											

V Crop Selling Activities

Type of Crop	Market														
	Village					Local Market					Distant Market				
	quantity	per (period)	price	Sell per year	Tot. Reven	quantity	per	price	Sell per year	Tot. Revenue	quantity	per	price	Sell per year	Tot. Revenue
White Teff															
Mixed Teff															
Red Teff															
Wheat															
Barley															
Maize															
F.peas															
H.beans															
Nug															
Linseed															
Rape Seed															
Sub Total															

VI Livestock Production Activities

	Animal Type	Number begining of year	Born during year	Died during year	Stolen during the year	Bought during year	Total end of year	Age at first Calving	Months in milking	Milk yield per day (local unit)
	Cattle									
1	Milking Cows (local)									
2	Milking cows (crossbred)									
3	Non-milking cows (local)									
4	Non-milking cows (crossbred)									
5	Oxen									
6	Heifers (*Gider*)									
7	Bulls (*Woifen*)									
9	Calves									
	Sheep									
1	Ewes									
2	Ram									
3	Lamb									
	Goats									
1	Does									
2	Bucks									
3	Kids									
1	Horses									
2	Mules									
3	Donkeys									

1. Number of oxen used in cropping last year ________________________________

Any additional bulls (*Woifen* or young oxen) used to assist oxen ______________________

Number of hours young bulls are used to assist oxen during the day ____________

Number of pairs (teams) of oxen used in cropping last year____________.

Number of oxen rented in/out ____________ to/from ____________ where. What is the average age at which a bull could be trained for traction ____________.

3. Cattle not used for threshing purpose____________.

Animals not used for threading the field before planting ____________

4. Rank sources of feed for animals according to importance (1 as most important).

a) Grazing on fallow (permanent grazing) lands and stubble ____________

b) Crop residues____________

c) Hay ____________

d) Others (specify)____________.

5. Do you preserve crop residues for animal feeding during the wet season? Yes________ No________.

6. Do you produce enough feed for animals all round the year? Yes ________ No________

If yes, which months are most critical in terms of shortage of animal feed?____________.

7. Which crops provide you the crop residue for animals?

Most important crops ____________

Less important crops ____________

8. Rank sources of household energy according to importance (1 as most important source).

a) Firewood collected from communal woodlot____________

b) Firewood from privately owned trees (eg. Eucalyptus, Acacia, etc)____________

c) Crop residues ____________

d) Dried cow dung____________

9. Which crops provide you the crop residue for use as firewood?

Most important crops____________

Less important crops____________

10. What are the major constraints for livestock production? Rank them according to importance.

a) Seasonal shortage of animal feed

b) Round the year shortage of animal feed

c) Drought

c) Seasonal shortage of water for animals

d) Diseases

e) Lack of markets and low prices for animal products

f) Lack of credit

g) Others (specify)____________

VII Livestock and Livestock Products Selling Activities

Animal/Animal Product	Market														
	Village					Local Market					Distant Market				
	Quantity	per period	price	Tot. Sell/year	Tot.re venue	quantity	per	price	Tot. sell/year	Tot.Re venue	quantity	per	price	Tot. sell/year	Tot. Revenue
Milking cows															
Non milking cows															
Oxen															
Heifer															
Bulls															
Calves															
Sheep (sex and age)															
Goats (sex and age)															
Horses															
Mules															
Donkeys															
Skin and hides															
Butter															
Chicken															
Eggs															
Dried animal dung															

1. Reasons for selling animals (list according to importance)
   a) Purchase of agricultural inputs (eg. fertilizer, seeds, hire labor, etc) ____________________
   b) Purchase of oxen ___________________________
   c) Purchase of food crops for home consumption___________________________
   d) Because of low productivity (eg. low milk yield)____
   e) Pay taxes and other social obligations ____
   f) Repayment of debts ____
   g) Reduce stock size due to shortage of feed____________________________________
   h) Good seasonal market and high prices for animals______________________________
   i) Others specify ____

VIII Environmental Conservation

1. Has the size of your land holding increased or decreased over the last years?

____

2. How many plots do you own on the uplands and lowlands?

Five years ago:

Uplands ____________________ Lowlands ____________________

At present

Uplands ____________________ Lowlands ____________________

Plot No.	Slope category	Vegeta tive cover	Area	Origin	Years of Ownership	conserved area & type	Type of modificat. introduced	Farmers perception of threat of soil erosion
Uplands Plot 1								
Plot 2								
Plot 3								
Plot 4								
Lowlands Plot 1								
Plot 2								
Plot 3								

* Vegetative Cover: 0 if bare (no trees except seasonal growth of weeds/grass), 1 if few trees (less than 3 per kert) are left, 2 if more than 3 trees are available per kert.

* Origin : 0 if inherited, 1 if hired, 2 if allocated by the PA, 3 if bought.

* Soil Conservation (area & type): Area of conserved cultivated land (in local units) followed by a comma and TR if traditional, LB if level bund, GB if graded bund, LF if level Fanja-ju, GF if graded Fanja-ju, GS if grass strips, or NO if no soil conservation practiced. (eg. 5 kert, TR).

* Type of modification: all bunds removed, some bunds removed, all bunds kept intact.

* Farmer's perception of the threat of soil erosion on that plot: 0 if no soil erosion, 1 if slight soil erosion, 2 if moderate soil erosion, 3 if high soil erosion.

1. Do you think you will own the land as long as you need it? Yes __________ No ___________.
2. Do you also think you could transfer the land to your children? Yes ________ No __________.
3. Are all the trees on your plot planted?
   a) All natural growth
   b) Some planted and some natural
   c) All planted
4. How many trees have your family and you planted on your plots in the last 5 years (give number and species) ____
5. Who owns the trees in your plots?
   a) It is open access
   b) Only members of the community and relatives
   c) It is under my own private ownership
6. Is there a shortage of trees for construction and fire wood? Yes __________ No __________
7. If yes, why are you not planting more trees every year?
   a) Shortage of land which could be spared for planting trees
   b) Shortage of labor
   c) Trees are not good for crop growth when planted in croplands
   d) Drought and poor survivability
   e) Why plant more trees if I have no security on ownership
   f) Free roaming animals in the dry season will destroy the seedlings
   g) Others (specify) ______________________________________
8. It is said that some years ago most of this area was covered by forest. Who has destroyed the forest and for what purpose?______________________________________
9. Can you mention any advantages of protecting forests in this area?

   ____

10. How about the disadvantages?

    ____

11. Which kind of wild animals are available in this area? (Give names in Amharic).

    Mammals

    Most commonly found ____

Rarely found ______

Disappeared ______

Birds

Most commonly found ______

Rarely found ______

Disappeared ______

12. Can you give some reasons for disappearance or rarity of some species of wild animals?

______

13. Has the number of any of the wild animals increased in recent years? Yes ____ No ____

If yes which specific species ______

14. Do you think the productivity of land has decreased overtime?

Yes ______ No ______.

15. If productivity of land has declined, what do you think is the problem? (list according to importance)

a) Natural phenomenon beyond the control of farmers ______

b) Lack of animal manure and fertilizers for improving the productivity of land ______

c) Shortage of oxen and/or labor leading to poor preparation of land before planting ______

d) Water and wind erosion which depletes the land of the fertile top soil ______

e) Others (specify) ______

16. Do you have a radio? Yes ______ No ______. Have you ever heard from the radio or from the extension agents of the Ministry of Agriculture that soil erosion is reducing the productivity of the land in this area? Yes ____ No ____. Do you think what they say is true? Yes ____ No ____.

17. Do you know of any plot in this area which has been degraded due to excessive soil erosion?

Yes ______ No ____. Can you give a reason why such a plot was more eroded than others?

______.

18. If soil erosion is gradually eating the fertility of the soil what do you propose as a solution?

a) There is no solution which I know of.

b) Use of fertilizer to compensate for lost soil nutrients

c) Traditional soil conservation

d) Improved soil conservation

e) Taxing the farmers whose careless actions lead to more soil erosion

f) Others (specify) ______

19. Do you think you have the responsibility to conserve the soil in your crop land? Yes ____

No______.

20. Do you think any one else is responsible for conserving the soil in your crop land? Yes ______ No ______ If yes, whom and in what way? ______.

21. If traditional soil conservation is not sufficient to conserve the soil, what else do you think has to be done to conserve the soil? ______

22. Do you practice introduced soil conservation techniques? Yes __________ No ___________

What is the problem with the introduced soil conservation techniques?

a) Are not convenient for plowing once the structures are built

b) Construction takes scarce land out of production

c) Crop yields on treated and untreated land are more or less the same and thus had little incentive to practice introduced soil conservation

d) Construction of structures is highly labour demanding

e) Construction of structures is highly expensive and thus most farmers can't afford to adopt them.

f) Structures harbour pests (eg. rats, etc) which destroy crops

g) Others (specify) ________________________.

23. Do you use animal manure for enhancing soil fertility? Yes ____________ No _______________

How about as firewood? Yes _________________ No _______________________

When do you start to use animal dung as source of household energy? ______________________

Which crops do you grow using animal manure? ___________________________.

24. What is the problem of using animal manure on all plots?

a) Long distance from homesteads

b) Some crops don't grow well with animal manure

c) Use of dung as firewood leaves little for use as fertilizer

d) Shortage of animal manure due to few animals

e) Others (specify) ____

25. Comment on human population over the last years

a) Remained the same b) Declined over time c) Increased over time

26. Comment on livestock population over the last years

a) Remained the same b) Declined over time c) Increased over time

27. Comment on relation between population pressure and land degradation

a) has led to disappearance of forests and scarcity of agricultural land

b) has reduced forests and agricultural land but no effect on productivity of land

c) population pressure has no effect on resource scarcity and land degradation

28. What should be done to reduce human population?

____

29. Do you think reduction in livestock numbers is desirable to reduce overgrazing? Yes ______________ No _________________. If yes, what has to be done to reduce the animal number?______________________________________.

IX Other Sources of Household Income

Source	Who in family earned	Over period	Village market				Local Market				Distant Market			
			Price	Quantity	From/to & where	Tot. Reven	Price	Quantity	From/to & where	Tot.Revenue	Price	Quantity	From/to & where	Tot. Rev
Hiring Oxen (number)														
Hiring Labor (months)														
Renting land														
Migration (months)														
Firewood														
Government transfers														

Source	Who in family earned	over period	village market				Local market				Distant market			
			price	quantity	From/to & where	Tot. rev	price	Quantity	From/to & where	Tot. reven	price	Quantity	From/to Where	Tot. reven
Sell of honey														
Sell beverages (*Tella, etc*)														
Sell of Handicrafts (village prod.)														
Gifts **Clothes** man														
woman														
child														
Shoes man														
woman														
child														
Brides price														

X Transfers to Other Households - Free Transfers

Item	To whom	Where lived	Quantity	Per period	Total transfers
Crops 1.					
2.					
3.					
Animals 1.					
2.					
Cash					
Others (state) 1.					

XI Other Expenditures

Item	Amount	Per Period	To Whom	Where lived	
Education					
Health clinic					
Land use fee					
Other taxes					
Church					
Healer					
Edir					
Others					

XII Factor use per kert of cropping activity or per herd of animals per year.

Activity	Teff Upland		Teff Lowland		Wheat Upland		Wheat Lowland		Lentils Upland	
	Oxen (days)	Labor (mandays)	Oxen	Labor	Oxen	Labor	Oxen	Labor	Oxen	Labor
Soil Conservation										
1st Plowing										
2nd Plowing										
3rd plowing										
4th plowing										
5th plowing										
Planting										
Fencing										
1st weeding										
2nd weeding										
Harvesting										
Threshing										
Grain Transport										
Straw Transport										

'Cont'd

Activity	Barley Upland		F.bean Upland		F.pea Upland		C.pea Lowland		R.pea Lowland		Other crops		Animal Prod.
	Oxen	Labor	Oxen	Labor	Ox	Labor	Ox	Labor	Ox	Labor	OX	Labor	Labor
Soil conservation													
1st Plowing													
2nd Plowing													
3rd plowing													
4th plowing													
Planting													
Fencing													
1st weeding													
2nd weeding													
Harvesting													
Threshing													
Grain transport													
Straw transport													
Animal herding													
Kraaling													
Feeding & watering													
Firewood & dried dung collection													

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This study, examines factors that deter conservation of the soil stock, and analyzes various economic and institutional incentives that may be employed to enhance sustainable land management in peasant agriculture. The thesis consists of four articles that address the land degradation externality and polices for sustainable land management, spanning a dynamic and a nonseparable farm-level programming model, an econometric study of actual peasant soil conservation behaviour, and policy simulations. A benefit-cost approach is employed for analyses of the Pareto efficiency of specific policy instruments. Policy simulations include various incentives linked to conservation (cross compliance and cost sharing) and pricing policies.

A synthesis of the major findings and theoretical analyses of the land degradation-food security problem in Ethiopia is given in a summary article.

Prof. Stein T. Holden was the advisor for this dissertation.

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