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The Cost of Land Degradation in Ethiopia:
A Review of Past Studies

Acknowledgments

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Acronyms and Abbreviations

ADLI	Agricultural Development Led Industrialization
AGDP	Agricultural gross domestic product
AMC	Agricultural Marketing Corporation
Br	Birr
CPSZ	Crop Production Systems Zone
DAP	Diammonium phosphate
EHRS	Ethiopian Highland Reclamation Study
FAO	Food and Agriculture Organization of the United Nations
GAIL	Gross Annual Immediate Loss,
GDCL	Gross Discounted Cumulative Loss
GDFL	Gross Discounted Future Loss
GDP	Gross domestic product
GIS	Geographic information systems
NCSS	National Conservation Strategy Secretariat
PPP	Purchasing power parity
SCRP	Soil Conservation Research Project
SLM	Sustainable Land Management
SNNPR	Southern Nations, Nationalities, and People's Region
TLU	Total livestock unit
UNDP	United Nations Development Programme
UNEP	United Nations Environment Program
USLE	Universal Soil Loss Equation
WBISPP	Woody Biomass Inventory and Strategic Planning Project
WRSI	Water Requirements Satisfaction Index

Abstract

This paper reviews past studies on the costs of land degradation in Ethiopia, with a view to drawing implications for policies, programs, and future research on sustainable land management (SLM). The following studies are reviewed in detail: the Ethiopian Highlands Reclamation Study (EHRS) (FAO 1986); the Soil Conservation Research Project (SCRP) (Hurni 1988); the National Conservation Strategy Secretariat (NCSS) (Sutcliffe 1993); the World Bank Reassessment (Bojö and Cassells 1995); Sonneveld (2002); and the Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2001a,b,c; 2002; 2003a,b; 2004a,b).

Given the wide range of methods and assumptions used in the studies, their findings concerning annual costs of land degradation relative to agricultural gross domestic product (AGDP) are of remarkably similar magnitude. The minimum estimated annual costs of land degradation in Ethiopia range from 2 to 3 percent of AGDP. This estimate does not take into account downstream effects such as flooding, suggesting that actual total costs are possibly much higher than the 2–3 percent range. A onetime occurrence of a 2–3 percent reduction in AGDP might be manageable, but the cumulative losses to land degradation over time are very serious for an agriculturally based economy. Such cumulative losses represent a significant drag on rural growth and poverty reduction and jeopardize long-term, sustainable development.

1.0 Introduction

In Ethiopia, land degradation, low and declining agricultural productivity, and poverty are severe and interrelated problems that appear to feed off each other. In light of the increasing population (2.2 percent growth per annum) and the low levels of urbanization (only 16 percent of the population live in urban areas), all projections indicate that land degradation in Ethiopia is bound to proceed at aggravated rates unless significant progress is made in conservation, rehabilitation, and restoration.

The irony is that the natural resource base is central to the livelihood of a high proportion of Ethiopia's population and distinctively critical to the national economy. Eighty-five percent of the 70 million people in Ethiopia depend, albeit insufficiently, on land for survival. Agriculture accounts for 50 percent of gross domestic product (GDP) and 85 percent of foreign exchange earnings. In fact, the Agricultural Development Led Industrialization (ADLI) strategy—one of the government's principal growth strategies—anticipates that agricultural growth will underpin and bolster industrial development. If urgent measures are not taken to arrest Ethiopia's serious land degradation, the country is headed for a "catastrophic situation" (Getinet and Tilahun 2005).

Recent reports on the several dimensions and processes of land degradation in Ethiopia reveal:

- The loss of 30,000 hectares annually from water erosion (more than 2 million hectares have already been damaged severely) (National Review Report 2002).
- A total loss of 4,000 hectares on state farms owing to severe salinization.
- An estimated one billion tons of topsoil lost each year (Tefetro 1999).
- Nutrient depletion of 30 kilograms of nitrogen per hectare and 15–20 kilograms of phosphorous per hectare (UNDP 2002).
- The loss of 62,000 hectares of forest and woodland annually (World Bank 2001).

What does land degradation of this nature and magnitude actually cost the Ethiopian economy? Land degradation has direct and indirect costs. Among other things, direct costs include:

- The costs of nutrients lost through topsoil erosion (or the cost of replacing these nutrients).
- The production that is lost because of nutrient and soil losses.
- The costs of forest removal.
- The loss of livestock carrying capacity.
- The decline in cropped area.

Indirect costs mainly include:

- The loss of environmental services.
- The silting of rivers and dams.
- Increasing irregularity of streams and rivers.
- Reduced groundwater reserves.
- Flooding.
- Other costs, related to social and community losses from malnutrition, poverty and migration.

Some of these costs can be quantified, but others are much more difficult to estimate (Bojö and Cassells 1995). Even so, several studies over the last few decades have sought to impute a quantitative cost to land degradation in Ethiopia. They have reached widely varying conclusions regarding the nature, extent, and economic cost of land degradation, largely because they have used differing methodological approaches and underlying assumptions. A further complication is that they report the costs of land degradation differently, which makes it difficult to compare the studies or to use them as the basis for policy and program decisions related to sustainable land management (SLM). Despite these limitations, a review of these studies yields insights on potential future directions in policies, programs, and research related to SLM.

2.0 Estimating the Cost of Land Degradation: Conceptual Issues

A number of conceptual issues impinge on estimates of the cost of land degradation, the most important of which are semantic or definitional conjectures. For example, it is important to differentiate between *land* degradation and *soil* degradation. These terms are often used interchangeably but are not necessarily synonymous.

Land degradation is a broad, composite, and value-laden term that is complex to define but generally refers to the loss or decline of biological and/or economic production. UNEP (1992) defines land degradation as a reduction of resource potential by one or a combination of processes—including water erosion, wind erosion, a long-term reduction in the amount or diversity of natural vegetation, salinization, or sodification—acting on the land.

Soil *degradation* is a narrower term: soil degradation is a component of land degradation. It refers to a process that lowers the soil's current and/or potential capacity to produce goods or services. Six specific processes are recognized as the main contributors to soil degradation: soil erosion, wind erosion, waterlogging, excess salts, chemical degradation, biological degradation, and physical degradation.

Most cost estimates of land degradation do not distinguish between soil erosion, soil degradation, and land degradation, and many studies have misconstrued soil degradation and soil erosion to be synonymous with land degradation. Because these studies neglect the impacts from lost vegetation, chemical and/or biological soil degradation, and other processes (where they exist), their results only partially estimate the cost—and hence greatly obscure the true cost—of land degradation. Understanding the contribution of each component of degradation to the total cost of land degradation is vital, not only for appreciating the type and degree of the problem but also for pinpointing appropriate policy interventions.

Another conceptual issue is related to aggregating or scaling up the cost of land degradation. On-site costs of land degradation are always estimated at a small scale, such as the plot, farm, or village, and then scaled up to the farming system, regional, or national level. In scaling up, authors usually identify landscape units for which they expect the same or similar impacts, add up the annual costs of soil degradation for each unit, and thereby derive the total cost of degradation nationwide (Bishop 1995). According to Enters (1998), this approach has several limitations. It wrongly ignores possible price effects of differences in total agricultural production resulting from land degradation. It does not allow for a change in crop choice over time, although farmers, in response to declining productivity, may change to less nutrient demanding or less erosive crops. Finally, the cost of land degradation does not depend solely on biophysical process but is an artefact of other social and economic variables, such as crop prices, off-farm employment opportunities, discount rates, credit availability, and farmers' perspectives.

Yet another conceptual issue is related to the fact that many processes of degradation have on- and off-site impacts. In the case of erosion, for example, once soil and excessive runoff leave the boundaries of individual farms, they cause off-site or off-farm impacts, resulting in costs or benefits that are external to the farm household. In addition to these downstream impacts, which are usually felt mostly within catchments and national borders, there can also be international and global impacts of land degradation, such as climate change, biodiversity loss, and pollution of international waters (Pagiola 1999). Most studies estimating the costs of land degradation restrict themselves to on-site impacts; the analysis of off-site effects,[1] although frequently recommended, is rare. It is usually conducted only in qualitative terms because it is difficult to measure such impacts. The implication is that tendered values often underestimate actual costs.

3.0 Scope of This Review

A number of studies deal with and estimate the on-site costs of land degradation in Ethiopia. The main works reviewed in this paper are:

- The Ethiopian Highlands Reclamation Study (EHRS) (FAO 1986).
- The Soil Conservation Research Project (SCRP) (Hurni 1988).
- The National Conservation Strategy Secretariat (NCSS) (Sutcliffe 1993).
- The World Bank's reassessment (Bojö and Cassells 1995).
- Sonneveld (2002).
- The Woody Biomass Inventory and Strategic Planning Project (WBISPP 2001–04).

The first four studies (EHRS, SCRP, NCSS, and Bojö and Cassells) focus on the Ethiopian highlands, which cover only 44 percent of the country's area. At first glance they do not appear to provide a national perspective, but given that 90 percent of the human population, about two-thirds of the livestock population, and well over 90 percent of the regularly cropped land are in the highlands, results of these studies may be fairly representative. Some of the studies are based on data preceding 1993, implying that national data include Eritrea, which was part of Ethiopia at that time.

3.1. The Ethiopian Highlands Reclamation Study (EHRS)

Objectives and methods. The EHRS is the most comprehensive and detailed study addressing land degradation in Ethiopia. It was conducted to analyze and explain the processes, causes, extent, and types of degradation in the highlands, identify the areas and peoples most critically affected and/or threatened, estimate the rates and costs of degradation in different locations (both then and in the future), assess the need to tackle degradation (in terms of alternative development options), and evaluate what was already being done to combat and/or avoid degradation. The EHRS recognized water and wind erosion and chemical, physical, and biological degradation as the main degradative processes in Ethiopia, but it concluded that soil erosion and biological degradation were the most important.

Land degradation impacts were assessed in social and economic terms only for soil erosion. Four types of costs were specified: lost cropland, lower crop yield, lost grazing land, and lower grass yield. These costs were compared to costs incurred in the absence of soil erosion. The extent of erosion was estimated using soil depth and geomorphological maps, while estimates of gross soil erosion rates were based on the FAO method derived from the Universal Soil Loss Equation (USLE). It was assumed that 80 percent of the total gross soil loss was from cropland, whereas most of the remaining 20 percent was from overgrazed grassland and a little from wasteland and other land. Ninety percent of the eroded soil was assumed to be redeposited evenly across land use types. The analysis conservatively assumed that rates of soil erosion would be constant over a 25-year period (1985–2010) and that agricultural productivity would not change. No formal

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[1] Not all off-site impacts of land degradation are negative. For example, soil erosion may bring beneficial inflows of soil and plant nutrients to farmers downstream. Increased runoff in uplands may also be captured and used by farmers or other water users downstream.

model was presented for yield reduction estimates; rather, estimates were based on educated guesses using international evidence and studies. Estimates of reductions in crop and grass production were derived for the 25-year period and then subjected to sensitivity analysis to examine how they might change under alternative assumptions. A productivity loss of 2 percent per annum was applied to the entire crop production area irrespective of soil depth.

A discount rate of 9 percent was used in computing the present value of costs of degradation.[2] Crop prices paid by the Agricultural Marketing Corporation (AMC) were used, but these were between 20 and 30 percent lower than market prices at the time of the study. While downstream costs and most social costs were not included, estimates of the number of persons affected and some social costs were provided. Any farming benefits accruing from deposition of eroded sediment were assumed to be insignificant and short-lived.

Major findings. The EHRS estimated that in the mid-1980s 27 million hectares (almost 50 percent of the highland area) were significantly eroded, 14 million hectares were seriously eroded, and over 2 million hectares of farmland were beyond reclamation. Over half of the area estimated to be without significant accelerated erosion was nevertheless considered at risk, because it was likely to be cropped in the future, and the soils were inherently prone to erosion. Only about 10 million hectares (approximately 20 percent of the highland area) were considered to be fairly free of the risk of serious accelerated erosion.

About 90 percent of the eroded soil (1,700 million tons) was assumed to be redeposited every year in lower-lying areas. Erosion rates were estimated at 130 tons per hectare per year for cropland and 35 tons per hectare per year for all land in the highlands, but even at the time these estimates were regarded as high. If rates of erosion remained unchanged, the study projected that by 2010 about 100,000 square kilometers (about 18 percent of highland area) would be bare rock. In addition to the 20,000 square kilometers incapable of sustaining arable cropping in the mid-1980s, it was predicted that another 76,000 square kilometers were likely to be similarly degraded by 2010. This claim contrasts with actual land use trends, which have not shown much change in arable or permanent cropland in Ethiopia since the early 1990s (FAOSTAT 2005).

The annual soil losses and corresponding reductions in crop and grass yields (as a percentage of the 1985 yields) for the three highland zones are presented in table 1. Overall, the predicted average annual yield loss in the highlands, compared to the 1985 level, was 2.2 percent for crops and 0.6 percent for grass. Sensitivity analysis for "low" and "high" yield-loss scenarios suggested that average annual yields would decline by 0.6 percent for crops and 0.3 percent for grass under the "low" scenario and by 3.4 percent for crops and 1.1 percent for grass in the "high" scenario.

Table 1: Estimated annual soil losses and corresponding yield reductions in the highlands, by zone

		Average annual yield decline (% from 1985 level)					
	Average annual soil loss as percentage of 1985 soil depth	**Used for main analysis**		**Range used for sensitivity tests**			
				Low		**High**	
Zone		**Crops**	**Grass**	**Crops**	**Grass**	**Crops**	**Grass**
Low-potential cereal	0.5	3	1	1	0.5	5	2
High-potential cereal	0.4	2	0.5	0.5	0.25	3	1
High-potential perennial	0.2	1	0	0.25	0	1.5	0.25
Total highlands*	0.3	2.2	0.6	0.6	0.3	3.4	1.1

Source: FAO 1986.
Note: * indicates average weighted by respective land areas.

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[2] This rate was the interest rate for agricultural loans in Ethiopia in the mid-1980s and is considered to approximate the opportunity cost of capital (FAO 1986:201)..

The reduction in national grain production from soil erosion was estimated at about 2 percent per annum. The equivalent in terms of cereal production lost in the early 1980s exceeded 120,000 tons per annum, losses that were expected to increase substantially over time. The present value of costs of degradation over the 25-year period after the mid-1980s was estimated at 4,200 million birr (Br), equivalent to an average annual reduction of over 2 percent of agricultural GDP (AGDP) in 1982/83.

A major weakness of the EHRS was its reliance on poor-quality, limited, site-specific data for estimating soil loss rates. As noted, soil erosion rates were modeled following the USLE approach (Wischmeier and Smith 1978), whose validity limits have been challenged by many, including the original authors (Evans and Kalkanis 1976; Wischmeier and Smith 1978; El-Swaify, Dangler, and Armstrong 1982; Stocking 1982). Nor does the study use a formal model to estimate the effects of erosion on yield, and this limitation, combined with assumptions such as the use of depressed crop prices relative to prevailing market prices, led to errors in estimating the costs of land degradation.

3.2. The Soil Conservation Research Project (SCRP)

Objectives and methods. The SCRP was a Swiss Government-funded project jointly implemented by the Ministry of Agriculture and the University of Berne to conduct soil conservation research in Ethiopia from 1981 to the mid-1990s. According to Bojö and Cassells (1995), the research program was conducted at three levels: a national exploratory survey on rainfall erosivity; the collection of regional and district data on land use; and the collection of catchment and plot data on soil conservation.

Like the EHRS, the SCRP study (Hurni 1988) assumed that soil erosion caused by water was the most important land degradation process. The soil erosion hazard on various land types (table 2) was modeled using the USLE adapted to Ethiopian conditions. According to Hurni (1988), the simulated results correlated well with test-plot measurements made under the SCRP. The study reported gross soil losses (not net of redeposition and soil formation) and compared soil formation to gross soil losses to assess system sustainability.

Main findings. Rates of gross soil loss reported in the SCRP study for various land types (as defined in the EHRS) are shown in table 2. The average soil erosion rate nationwide was estimated to be 12 tons per hectare per year, for a total soil loss of 1,493 million tons per year. The soil erosion hazard was much higher for annual cropland compared to land under grazing, perennial crops, forest, and bush. Thus, in spite of covering only 13 percent of national area, annual cropland contributed about 45 percent of the estimated soil loss. There was also considerable variation in soil loss rates by agroecological zone (dry and hot lowlands, moist middle slopes, and cold and wet highlands). Rates were highest for cultivated slopes in the Dega highland zone (2,300–3,200 meters above sea level). Soil loss estimates reported in the SCRP study are more accurate and reliable compared to those in the EHRS study. They were calibrated against field measurements, and a more detailed classification of soil textures was used in deriving the erodibility hazard. Bojö and Cassells (1995) found that Hurni's (1988) soil loss estimates translated into a 2 percent decline in agricultural production per year.

Table 2: Estimated gross soil loss rates by land cover type

Land cover type	Area (%)	Soil loss (t/ha/yr)	(million t/yr)
Annual cropland	13.1	42	672
Perennial crops	1.7	8	17
Grazing and browsing land	51.0	5	312
Currently unproductive (formerly cropland)	3.8	70	325
Currently uncultivable	18.7	5	114
Forest	3.6	1	4
Wood and bushland	8.1	5	49

Source: Hurni 1988, Bojö and Cassells 1995

3.3. The National Conservation Strategy Secretariat (NCSS)

Objectives and methods. Using additional data, Sutcliffe (1993) revised the EHRS estimates and presented new values for the magnitude and on-site impacts of soil erosion in Ethiopia. He also analyzed the impact of nutrient losses from removal of dung and crop residues. Using Hurni's (1988) soil erosion rate estimates and a Stocking and Pain (1983) soil life model as the analytical framework, Sutcliffe established the minimum soil depth required for cultivating different crops and the soil depth threshold (90 centimeters) beyond which erosion does not immediately affect crop productivity. He used a model developed by FAO to derive a Water Requirements Satisfaction Index (WRSI) from monthly rainfall, water-holding capacity, evapotranspiration, and crop water requirements. Relative reductions in crop yield were then related to the WRSI. The EHRS estimates of crop mix, absolute yields, and areas for three altitudinal ranges and three major agroecological zones (high-potential perennial, high-potential cereal, and low-potential cereal) were used to project losses in crop production. Losses in crop residue production were converted to tropical livestock unit (TLU) equivalents. Financial implications of the results were estimated using market prices in 1985/86, while world market prices were used to determine the economic impact for society.

Sutcliffe built on a methodology developed by Newcombe (1984) to analyze the impacts of breaches that occur in the nutrient cycle when dung and residue are used as fuel rather than soil amendments. Using the Ethiopian National Energy Commission estimates of dung and residue use for energy, Sutcliffe calculated the amount of nitrogen and phosphorus in dung and residues that was lost and the corresponding crop production loss. In addition, the burnt crop residues were evaluated in terms of their potential value as livestock feed, converted into potential increases in TLUs, and then priced. The replacement value of nutrients lost was calculated using the price of chemical fertilizers.

Main findings. Sutcliffe's soil erosion damage estimates are presented in table 3. His estimates of crop production losses and cropland losses for 1985 were only about 7 percent and 6 percent of the respective EHRS estimates.

Table 3: Estimated soil erosion damage

Nature of damage	Year	Damage estimate
Lost crop production (000 t)	1985	9
	2010	332
Lost cropland (000 ha)	2010	489
Lost pasture (000 ha)	2010	5,747

Source: Adapted from Sutcliffe 1993 by Bojö and Cassells 1995.

Total crop loss due to erosion and nutrient cycle breaches was about 0.5 million tons in 1985 (the base year for the calculations). When livestock losses were added, a total monetary cost of Br 581 million in 1985 was derived. Costs of breaches in the nutrient cycle were much higher than the costs of erosion. For example, it was estimated that in 1990, almost half a million tons of grain and more than one million TLUs were lost as a result of breaches in the nutrient cycle.

According to Bojö and Cassells (1995), the estimates of EHRS and Sutcliffe differed for several reasons: Sutcliffe used Hurni's gross soil loss estimates, which were lower than those used in the EHRS; the EHRS used a uniform loss in productivity of 2.2 percent per annum for the entire crop production area, regardless of soil depth, but Sutcliffe assumed that crop losses set in only when soil depth was less than 90 centimeters; the EHRS included about 21.1 million hectares of "open and wooded grassland" in its definition of "cropland"; and the EHRS applied a percentage increase in noncultivable area to all land in the highlands (not only cropland), which increased the estimated area of "cropland" loss to 7.6 million hectares in 2010.

Bojö and Cassells (1995) identified a number of drawbacks in the Sutcliffe (1993) study. First, an element of double counting may be involved in relation to the use of residues or dung as fuel and their opportunity cost in terms of lost crop production (including loss of future residue production). Since there is the additional option of feeding residues to livestock, the opportunity cost is the higher of the two use values. But they cannot logically be added. Adjusting for this discrepancy would revise Sutcliffe's estimate downward by more than 20 percent. Second, some double counting was probably involved in estimating the cost of livestock losses that occur when residues are burned and not used as feed. The sum of the value of flow products and services from livestock and the value of livestock as a "store of wealth" was taken as a measure of the cost. The market value of livestock should reflect the net value of the total flow of goods and services that emanates from the livestock over its expected (remaining) lifetime plus the store of wealth value and other intangibles, so double counting will occur, since the flow values are accounted for separately. Moreover, the investment before the sale of livestock was not deducted when calculating the net value of the entire (remaining) life cycle of a livestock unit. Third, an implicit assumption was that the nutrients in dung and residues were readily available for plants, in the sense that these nutrients were perfect substitutes for commercial fertilizer. This assumption is more likely to be true for dung than for residues, but it may not hold even for dung, depending on how this input is managed.[3] Thus Sutcliffe probably overstated the costs associated with burning dung and crop residues.

3.4. World Bank Reassessment

Objectives and methods. Following a review of previous major studies on land degradation in Ethiopia, Bojö and Cassells (1995) reassessed the costs using concepts of economic costs defined in terms of (1) the counterfactual scenario assumed and (2) the time horizon used. They used three concepts of economic loss in their work: gross annual immediate loss (GAIL), gross discounted future loss (GDFL), and gross discounted cumulative loss (GDCL) (see Annex 1 for definitions of these concepts). In estimating the cost of land degradation, Bojö and Cassells mainly followed Sutcliffe's (1993) approach, in which soil erosion and nutrient losses were taken into account. They argued that because of redeposition the net soil loss from cropland was probably on the order of half or less of the gross figures reported in previous analyses (such as Sutcliffe and EHRS). Where data were available, the weaknesses of Sutcliffe's study were addressed to arrive at revised cost estimates.

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[3] When manure is not covered, much of the nitrogen can be lost to the atmosphere. If the nitrogen content of manure is too low relative to the carbon content, it can actually reduce crop yields in the near term by reducing the availability of soluble nitrogen to plants (Giller et al. 1997).

Using a matrix derived by Sutcliffe (1993), Bojö and Cassells (1995) related various rates of soil loss with relative declines in yields. An average decline of 0.4 percent per year was obtained for all cereals. This figure for the yield impacts of erosion is similar in order of magnitude to most estimates obtained in studies elsewhere (for example, Pagiola and Bendaoud 1994; Crosson 1995; Oldeman 1998; Wiebe 2003). Based on Sutcliffe's analysis, a critical depth of 100 centimeters was assumed for all crops. Bojö and Cassells thus assumed that the effect of soil erosion was negligible in the short term where soil depth exceeded 100 centimeters. This was the case on 69 percent of cropland, so Bojö and Cassells calculated the effect of soil loss on crop yield for only about 30 percent of cropland. By taking the effect of redeposition into account, Bojö and Cassells also modified Sutcliffe's estimates of decreased feed availability owing to lower crop yields on eroded soils. Based on estimates of redeposition, and assuming that productivity impacts were approximately linear within the minimum and maximum soil depth thresholds assumed by Sutcliffe, Bojö and Cassells reduced Sutcliffe's erosion damage estimates roughly by one-half.

Bojö and Cassells noted that "removal of crop residues does not constitute 'land degradation' in a meaningful sense of the word, as the residues are taken from their best alternative use as livestock feed to be used as fuel." They therefore removed crop residues from the calculation of estimates of total nutrient loss. They then used the basic model employed by Newcombe (1984) and Sutcliffe (1993) to reconstruct scenarios using functions that relate dung quantities removed to nutrient content and nutrient loss to crop loss (six kilograms of crop loss per kilogram of nitrogen or phosphorus).

Since Sutcliffe's estimates used 1985/86 as the base year, Bojö and Cassells (1995) converted the effect on crop yields into monetary values in 1994 using the average rate of inflation and the retail price index for Addis Ababa.[4] They used a discount rate of 10 percent in their calculations of GDFL and GDCL (the World Bank standard for public investment projects). An infinite time horizon was assumed for computation of GDFL, while a period of about one century was considered for GDCL calculations. In computing GDCL, an annual growth rate of 2.5 percent was assumed for the use of dung and residues, based on the expectation that demand would increase in the future partly because of population growth. Assuming limits to the livestock herd and dung production, and limits to how much dung can be collected and returned to cropland, Bojö and Cassells imposed a cap of 20 million tons of dung.

Main findings. Bojö and Cassells modified Sutcliffe's (1993) estimates of soil loss rates to an average of about 20 tons per hectare per year. Their analysis led to the erosion and nutrient loss figures reported in table 4. Soil erosion, assumed to affect 30 percent of cropland, led to a grain loss of about 7,000 tons per year. Using a price of Br 1,431 per ton of grain in 1994, the value of grain lost due to soil erosion was Br 10 million. The cost of livestock feed that was lost when soil erosion reduced crop yields was estimated at Br 0.8 million in 1994 prices. Thus total current income of Br 10.8 million was sacrificed because of soil erosion.

Table 4: Land degradation costs (Br millions) in Ethiopia

	Erosion	**Nutrient loss**
Gross annual immediate loss (GAIL)	1×10^1	6×10^2
Gross discounted future loss (GDFL)	1×10^2	Na
Gross discounted cumulative loss (GDCL)	3×10^3	8×10^3

Source: Bojö and Cassells 1995
Note: na = data not available

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[4] Starting from a price per ton of Br 890 in 1985/86, they used an average inflation rate of 2.4 percent for 1986–90 and the retail price index for Addis Ababa for January 1991 and May 1994. The figure they arrive at is 890 x $(1.024)^5$ x 1.428 = Br 1,431.

The loss due to nutrient breaches was estimated at Br 626 million in 1994 prices. Thus the total GAIL from erosion and nutrient loss was Br 637 million,[5] equivalent to 3 percent of AGDP.[6] The GDFL from soil erosion with an infinite time horizon was estimated at Br 108 million. This figure represents the present value of the loss of productive capacity caused by soil erosion over an infinite horizon. The concept of GDCL is used because land degradation is a cumulative process, so layers of costs are added on top of each other. Using prices in 1994 and a 10 percent discount rate, the GDCL is estimated at about Br 3.4 billion (in present value terms). Using a discount rate of 10 percent, the GDCL for nutrient breaches for the period until 2100 was a present value of about Br 8.3 billion.

3.5 Sonneveld

Objectives and methods. Sonneveld (2002) estimated the impact of soil degradation on agricultural production in Ethiopia using two approaches: empirical (nonparametric) and engineering approaches. In the empirical approach, he estimated the impact of soil degradation on crop yields for dominant cereal crops using data from the UNEP/GRID (1992) work. In addition, he evaluated/simulated the effects of soil conservation and fertilizer application on future crop yields over 10 years by changing soil degradation and soil fertility levels and comparing the results with actual yields. Three scenarios were simulated:

1) No erosion control and no fertilizer use ("no control" scenario).
2) Soil conservation and no fertilizer use ("conservation" scenario).
3) No erosion control, but fertilizer use ("fertilizer" scenario).

In the simulation, the following assumptions were made:

- Soil degradation increases by 2.5 per cent per year or is controlled at its current level by soil erosion control.
- Soil fertility declines by 2.5 per cent per year or is maintained by fertilizer use at its current level.

The relationship between soil degradation and production was estimated using a nonparametric (kernel density) regression model for rainfed areas. The yield ratio (actual/potential yield) was used as the dependent variable (this adjustment of actual yield by potential yield was done to correct for agroecological and crop-genetic differences). The modeling compared yields in relation to indices of soil degradation and soil fertility. A cross-sectional dataset was used and comprised qualitative classifications of soil degradation and soil fertility, mean monthly annual rainfall, slope gradients, altitude, temperature, length of growing period, and yields of dominant cereal crops. All data were georeferenced to 460 map units of the Crop Production System Zones (CPSZ) (FAO 1998). The georeferenced data were overlaid with a UNEP/GRID (1992) map on soil degradation.

Whereas the empirical approach focused on annual cereal crops—neglecting perennial crops, livestock production, and the impact of overgrazing on soil erosion—the engineering approach evaluated the impact of soil degradation for the entire agricultural sector by combining spatial water erosion models with a spatial yield function that gave an estimate of the agricultural yield and its geographical dependence on natural resources and population distribution. Sonneveld used a spatial optimization model to calculate food production and income under alternative scenarios

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[5] This is the sum of Br 10 million (due to grain loss caused by erosion), Br 0.8 million (due to decreased livestock feed availability caused by erosion), and Br 626 million (due to nutrient losses).

[6] The AGDP figure used is based on what is reported for 1992, adjusted for inflation of the US dollar until 1994 (3.9 percent per year) (Bojö and Cassells 1995:36).

(table 5) of soil conservation, migration, and the development of nonagricultural sectors at the national level.

Table 5: Scenarios simulated in the optimization model

Scenario	Erosion control	Migration	Accelerated urbanization	Input
(1) Stationary	No	No	No	Low
(2) Control	Yes	No	No	Low
(3) Migration	Yes/No	Yes	No	Low
(4) Technology	Yes/No	Yes	Yes	High

Source Sonneveld 2002.

Soil loss was estimated using a combination of three spatial water erosion models: the USLE, expert model, and accessible data (accDat) model. The USLE was applied in areas with low rainfall erosivity. The expert model was applied to rangeland or areas where silt percentages were lower or equal to 40 percent. The accDat model was applied to all other combinations of land use or biophysical variables. The production impact of soil loss was expressed as the potential reduction in yield and area under cultivation that would occur if production potential dropped below a threshold value (specifically, below 20 percent of maximum potential yield). The relationship was tested by comparing simulated land productivity values with historical patterns. The test showed that the results were interpretable and more accurate than if straightforward reductions in yield or land area had been postulated for each geographical entity. The agricultural cost function used in the model (referring to purchased agricultural inputs) was calibrated as a quadratic function based on national and international statistics of agricultural inputs per hectare.

Main findings. Results from the empirical approach depicted a weak relationship between yield ratio and soil degradation. However, the analysis did identify that:

- Soil degradation had its major impact on soils of lower fertility and where population levels were low.
- On fertile soils, soil degradation was largely compensated by fertilizer application.
- Many areas, representing a high percentage of the population, were in a critical state, and the use of new external inputs and/or soil conservation measures was urgently required to compensate for lost soil fertility. The most vulnerable areas were in northern Ethiopia.

In simulation scenario 1 ("no control"), soil degradation and the loss of soil fertility were projected to reduce national crop yields by 22 percent over 10 years compared to actual yields. In this scenario, the northern provinces of Wollo, Gondar, and Tigray contained the degradation "hot spots" (the priority intervention areas). A similar spatial pattern of crop yield losses (20 percent average nationally) was found in the "conservation" scenario, indicating that soil conservation alone cannot compensate for declining soil fertility. In the last scenario ("fertilizer"), yield decreased by 6 percent, implying that fertilizer could mask the effects of soil degradation but would not by itself stop the decrease in productivity.

A major weakness of the empirical approach was the lack of a quantified soil degradation (soil loss intensity) variable. A soil degradation index was defined as a qualitative variable (nil, low, moderate, severe, very severe) for each CPSZ, based on the qualitative judgment of experts on erosion hazard.

Results of the optimization model (engineering approach) showed that in scenario 1 ("stationary"), national agricultural production per capita would plunge from US$ 372 in 2000 to US$ 220 in 2010. In this scenario, the average annual production decline (controlling for the effects of population growth) compared to the 2000 level was 2.93 percent (table 6). This decline is equivalent to a loss of US$ 5 billion from land degradation over 10 years (2000–10). The introduction of soil erosion control measures (scenario 2) was projected to increase production on average by 0.19 percent per annum—in stark contrast to results of the empirical approach, where yields under the "conservation" scenario were projected to decrease on average by 20 percent over 10 years at the national level.

In the "migration" scenarios, the productivity loss from soil degradation under the "restricted" and "free" migration alternatives was partly compensated by the occupation of more productive and less affected areas (table 6). However, losses in per capita revenues were still considerable, and the food supply remained far from the required levels. When soil conservation measures were taken, the migration scenarios gave much better results. Productivity was higher under the "free" scenario than under the "restricted" scenario for 2010. Soil conservation and migration to other productive areas supported slow growth in agricultural production, which did not suffice to meet expected food demand. With transregional migration, production in highly degraded areas was exchanged for production in less degraded sites. A shift to modern technology offered better prospects and moderated the migration, but soil conservation, especially in the long term, remained important.

A weakness of land degradation cost estimates derived from this approach stems from the failure to account for the cost of soil conservation in the analysis of agricultural revenue. This omission leads to overestimation of agricultural revenue or GDP. Prices of production vary, depending on the technology used, population size, season, increasing quality of products, and other variables, but Sonneveld used constant prices, ignoring price dynamics.

Table 6: Impact of soil degradation on food production: Summary of scenario results

Scenario	Soil conservation	Agricultural production (in US$ billions, PPP), 2010	Per capita agricultural production: rural population (in US$, PPP), 2010	Average annual production loss (gain) due to soil erosion (as % of AGDP),[a] 2010
(1) Stationary	No	12.4	220	- 2.93
(2) Control	Yes	17.8	324	+ 0.19
(3) Migration				
Restricted	No	15.9	283	-0.91
	Yes	23.2	412	+3.28
Free	No	16.9	300	- 0.32
	Yes	24.2	430	+ 3.8
(4) Technology				
Stationary (UN)	No	43.5	773	+ 14.89
	Yes	65.4	1163	+ 27.41
Stationary (AccUrb)	No	43.5	773	+ 14.89
	Yes	65.3	1661	+ 27.36

Source: Sonneveld 2002:192 and authors' calculations.

Note: The "Technology" scenario makes use of two alternatives for projecting rural labor force growth. The "UN" alternative uses UN predictions for population growth; the "AccUrb" (accelerated urbanization) alternative posits a higher outflow from the agricultural sector to industrial and service activities.

a Calculated as the yield difference between 2000 and 2010, controlling for population growth.

3.6 Woody Biomass Inventory and Strategic Planning Project (WBISPP)

Objectives and methods. This review made use of WBISPP reports on land degradation in several regions of Ethiopia. Although the reports cover most regions (albeit with different degrees of completeness regarding land degradation), no report was available for Oromia, forestalling derivation of any conclusions at the national level.

The WBISPP considered water erosion and biological degradation as the most important types of land degradation. The project used the same methods and basic assumptions as Sutcliffe (1993), although some changes were made in light of information available after 1993. Soil erosion factor controls for USLE initialization—rainfall erosivity, soil erodibility, slope length and steepness, and land cover and management—were obtained from geographic information system (GIS) data sets. Eight categories of soil loss were used to indicate the magnitude of soil erosion (table 7). As in Sutcliffe (1993), the concepts of maximum and minimum critical soil depth were used to estimate the impacts of soil loss on crop production. Estimates of annual and cumulative crop production and cultivated land lost were made for 2000–25.

Table 7: Soil loss classes

	Magnitude of erosion	
Class	(t/ha/yr)	(equivalent in mm of topsoil removed)
1	0–3.125	0–0.25
2	3.125–6 25	0.25–0.50
3	6.25–12.5	0 50–1.0
4	12.5–25	1–2
5	25–50	2–4
6	50–100	4–8
7	100–200	8–16
8	200–400	16–32

Source: WBISPP.

Costs of biological degradation were based on Sutcliffe's methods, with the changes in crop and dung nutrient content cited in Lupwayi, Girma, and Haque (2000): 1 ton of dry dung is equivalent to 11 kilograms of diammonium phosphate (DAP) (phosphorus equivalent) or 35 kilograms of urea (nitrogen equivalent); 1 ton of crop residues is equivalent to 1.1 kilograms of DAP (phosphorus equivalent) or 11 kilograms of urea (nitrogen equivalent). Dung for fuel collected from the household's own farmland was estimated for each region. The costs of nutrient breaches were estimated by converting the amount of nutrient lost into the equivalent in fertilizer, which was then converted into the equivalent crop loss. A nutrient-increment coefficient of 5 kilograms of cereal gain per kilogram of nutrient (N) was assumed.

Major findings. The percentage of total area for each soil loss class is shown in table 8 for each region for which data were available. Gross soil losses were 147, 5, and 27 million tons respectively for Amhara, Benshangul-Gumuz, and Tigray, while the corresponding net soil losses (the amount lost after accounting for redeposition) were 25, 0.8, and 5 million tons, respectively.[7] The soil loss rates were much higher for cropland than for the other land types.

Estimates of annual and cumulative crop losses from soil erosion for 2000–25 are presented in table 9. The cumulative loss is particularly significant because of the irreversible damage caused by soil erosion. For the Tigray and Amhara regions, crop and cultivated land lost due to erosion in 2000 was estimated to be below 1 percent of crop production and cultivated land. However, predicted crop and cultivated land lost for 2025 is about 3 percent of crop production and cultivated land in 2000.

Estimates of soil nutrients lost from burning dung and crop residues, and their equivalents in chemical fertilizer and lost grain production, are given in table 10.

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[7] Although net soil loss figures accounting for redeposition are estimated in the reports, the impacts on crop production are based on gross soil losses, as noted. The reports indicate that these estimates of soil loss are generally much lower than those reported in the Conservation Strategies of the regional states.

The plant nutrient losses and grain production foregone for an average family are shown in table 11. A comparison of cost estimates for soil erosion and nutrient breaches shows that in terms of annual losses, the costs of nutrient breaches are much higher than the costs of soil erosion, a finding similar to Sutcliffe (1993) and Bojö and Cassells (1995). In the long run, however, one needs to take into account the fact that soil erosion leads to irreversible damage.

Table 8: Percentage area subject to different degrees of soil loss, by region

		----------Soil loss class----------							
Area estimate	**Region**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Percentage of total area in region	Amhara	63	10	9	8	6	3	1	0
	Beneshangul-Gumuz	88	5	4	1	1	0	0	0
	SNNPR	37	4	19	26	3[a]	na	na	na
	Tigray	77	7	8	6	2	1	0	0
Percentage of cultivated land in region	Amhara	37	8	12	19	14	7	3	0
	Beneshangul-Gumuz	30	13	14	24	10	3	4	0
	Tigray	47	11	19	15	6	1	1	0

Source: WBISPP.

Note: Soil loss classes defined in table 7; na = data not available.

a This figure applies to a soil loss range of 25–200 t

Table 9: Estimated reductions in crop production in three regions, 2000–25, caused by soil loss within critical soil depths on cultivated land

(t grain)

Region	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Amhara	9,726	27,985	49,995	71,567	92,699	113,273
Beneshangul-Gumuz	509	1,413	2,451	3,400	4,270	5,087
Tigray	1,324	3,906	7,025	10,030	12,930	15,803

Source: Sonneveld 2002.

Table 10: Estimated crop nutrient losses incurred by burning crop residues and dung

	Fertilizer equivalent						
	Crop residues		**Dung**		**Total fertilizer**		
Region	**Urea**	**DAP**	**Urea**	**DAP**	**Urea**	**DAP**	**Grain production foregone (t)**
Amhara	30,787	3,079	80,053	25,160	110,840	28,238	203,030
Beneshangul-Gumuz	836	84	35	11	871	94	2,003
Harari					88	9	203
SNNPR					14,580	1,458	41,621
Tigray	1,277	128	9,263	2,911	10,541	3,039	24,112

Source: Sonneveld 2002.

Table 11: Estimated on-farm plant nutrient losses incurred by burning crop residues and dung

(kg/farm)

	Fertilizer equivalent						**Grain production foregone**
	Crop residues		**Dung**		**Total fertilizer**		
Region	**Urea**	**DAP**	**Urea**	**DAP**	**Urea**	**DAP**	
Amhara	10	1	26	8	32	8	73
Beneshangul-Gumuz	3.5	0.4	0.32	0.1	8.04	0.7	18
Tigray	3	0	20	6	23	7	52

Source: Sonneveld 2002.

Note: A "farm" is defined as a farm family.

4.0 Comparison of Results across Studies

Depending on the study, the estimated annual cost of land degradation in Ethiopia ranges from 2 percent to 6.75 percent of AGDP (table 12). The cost estimated by Sutcliffe (1993) is highest, because in addition to soil erosion, he accounted for costs associated with burning dung and crop residues. Bojö and Cassells (1995) revised downward Sutcliffe's (1993) estimates of the costs of burning dung and crop residues, and they also reduced his estimates of the cost of soil erosion to account for redeposition of soil, leading to an annual income loss estimate of about 3 percent of AGDP. Bojö and Cassells' estimate of the present value of future cumulative losses due to land degradation was much larger than this, but as a cumulative measure, it should not be compared to annual losses or annual agricultural income.

Table 12: Estimates of on-site cost of soil erosion in Ethiopia

Study	Degradation cost evaluation method	Discount rate and time horizon	On-site cost of degradation (% of AGDP)	Measure of cost
EHRS (FAO 1986)	Change of productivity (CP[a])	9% discount rate; 25-yr horizon	2.2	Annual average of cumulative costs over 25 years (similar to GDFL)
SCRP (Hurni 1988)	CP	Only immediate losses computed	2	Annual decrease in productivity
Sutcliffe (1993)	CP	Discount rate not available; 25-yr horizon	6.75	GAIL of nutrient losses, plus GDFL of erosion losses (GDFL < 1%)
Bojö and Cassells (1995)	CP	10% discount rate; 100-yr horizon	3	GAIL and GDFL (GDFL < 1%)
Sonneveld (2002)	CP	Discount rate not indicated; 10-yr horizon for empirical approach, 10- and 30-yr horizons for engineering approach	2.93	

Source: Adapted from Enters 1998, Bojö and Cassells 1995, and this review

a In this method of estimating land degradation costs, land degradation cost is equivalent to the value of the lost crop production valued at market prices (with future losses discounted by market interest rates).

The annual costs of land degradation estimated for Ethiopia in the reviewed studies are within the range of estimates for several African countries. For example, Bishop and Allen (1989) estimated costs of erosion in Mali to be 4–16 percent of AGDP. Bishop (1995) estimated costs of erosion to be 3–13 percent of AGDP in Mali and 17–55 percent of AGDP in Malawi. Although it is beyond the scope of this analysis to review the methods and assumptions of these other studies, it is clear that the range of on-site costs of land degradation estimated by the various studies for Ethiopia is not unreasonable as an order-of-magnitude estimate.

Several flaws associated with many or all of the Ethiopian studies may have caused significant errors in cost estimates of land degradation. As noted earlier, land degradation takes various forms, including soil erosion; deterioration of the physical, biological, or economic properties of the soil; and long-term loss of natural vegetation. With the exception of Sutcliffe (1993) and Bojö and Cassells (1995), the studies impute value only to soil erosion caused by water. Other forms of land degradation and downstream (off-site) effects were completely ignored in the analyses, most probably because data were lacking. These omissions cause the true costs of land degradation to be underestimated.

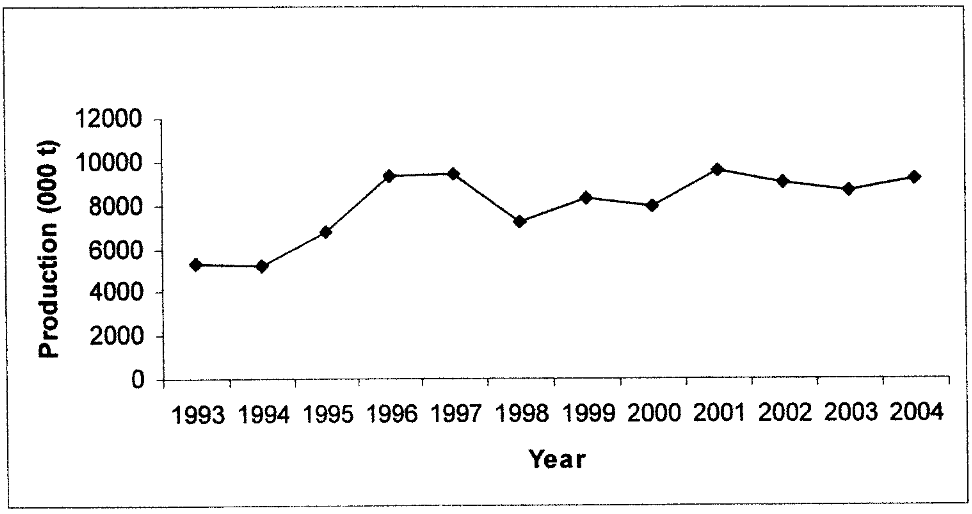
The soil erosion rates reported in many of the studies, with the exception of Bojö and Cassells (1995), did not take redeposition of soil into account. Even Bojö and Cassells' inclusion of redeposition was based on a crude assumption (a 50 percent redeposition rate, and an even distribution of redeposited soil across cropland). Because the actual effects on downstream productivity of redeposited soil are far from clear, it is difficult to say whether the reassessment conducted by Bojö and Cassells leads to an overestimate, an underestimate, or a reasonable estimate.

Soil erosion dynamics were not considered in any study except that of Sonneveld (2002), who arbitrarily assumed a 2.5 percent annual increase in soil erosion and 2.5 percent annual soil fertility decline. All the costs of soil erosion were computed with a constant price (no price changes) and soil erosion rates over the years. The impacts of land degradation on prices were not considered. Land degradation tends to reduce agricultural supply and hence increase prices of commodities (if they are not perfectly tradable), which would tend to reduce the costs of land degradation to farmers but increase them for consumers as a whole.

As seen from FAO data on production and land use patterns in Ethiopia, there was no significant decline in cropland use, crop production, or yields in Ethiopia over the last 20 years (figures 1 and 2), as predicted by some of the studies. The area of cultivated cropland has not changed to a large extent since 1993, contradicting dire predictions of the EHRS and Sutcliffe studies that large areas of cropland would be abandoned by 2010. Cereal yields have trended upward to some extent in the past decade, although with large annual variations. Part of this upward trend is likely due to increased use of fertilizer (figure 3), which may be in part a response to soil nutrient depletion and may be masking negative effects of soil erosion.

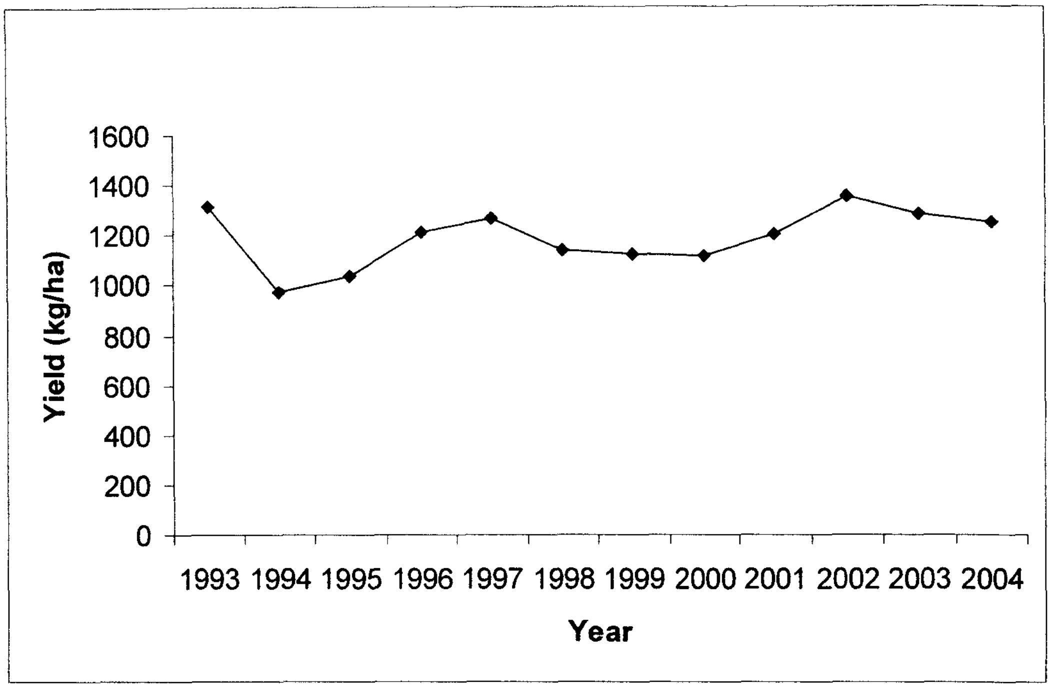
Without a more detailed study, it is impossible to ascertain whether the flaws in the reviewed studies caused the costs of land degradation to be over- or underestimated. Given the wide range of methods and assumptions used by the different studies for Ethiopia, it is remarkable that their findings are of similar magnitude concerning annual costs relative to AGDP. Of course, there are large differences in the estimated components of those costs, since several of the studies focused only on soil erosion, whereas those that focused on soil nutrient depletion from burning organic material found that this practice had a larger impact in the near term than soil erosion. Nevertheless, based on the available evidence, we believe that the true magnitude of annual on-site costs of land degradation in Ethiopia is likely to be in the order of magnitude of the range of estimates shown in table 8—that is, a few percent of AGDP per year.

Figure 1: National cereal production, Ethiopia



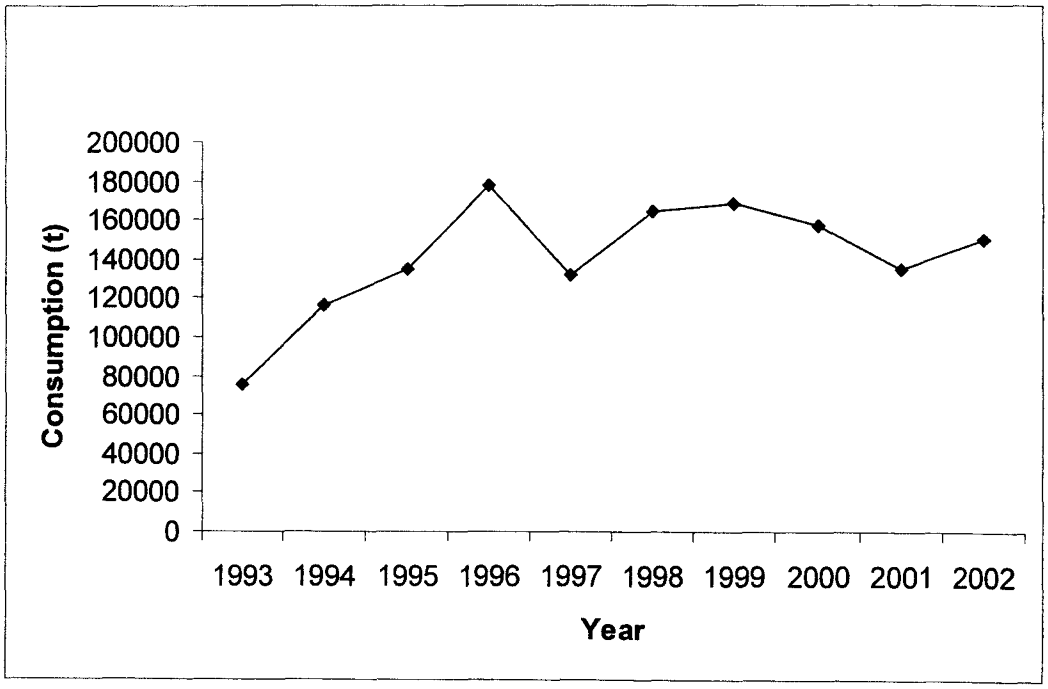
Source: FAOSTAT 2005.

Figure 2: National cereal yields, Ethiopia



Source: FAOSTAT 2005.

Figure 3: Fertilizer consumption, Ethiopia



Source: FAOSTAT 2005.

5.0 Conclusions and Implications

Despite considerable effort in the last few decades to estimate the on-site costs of land degradation in Ethiopia, this review suggests that all of the previous studies have produced only partial results subject to significant methodological and data weaknesses. Nevertheless, there is general agreement across the studies that the overall cost of land degradation in Ethiopia is substantial—probably in the order of a few percent of AGDP per year.

Some of the studies highlight particular land degradation "hotspots," such as large areas of Tigray, Wello, and Gonder, as emphasized by Sonneveld (2002). Furthermore, Sonneveld (2002) and other studies were based on earlier assessments of land degradation, and the situation may have changed markedly in the past few decades. It is not only low-potential areas where severe land degradation is occurring; for example, Gonder includes many high-potential agricultural areas. There is also evidence from more location-specific studies that severe degradation is occurring in some areas of very high potential, likely leading to high costs of land degradation per hectare. For example, Zeleke and Hurni (2001) found that their study area (Dembecha watershed in a high-potential area of Gojjam) lost 3 percent of its total land area between 1957 and 1995 due to land degradation, and 5 percent of the area reached critical soil depth (25 centimeters or less). Zeleke and Hurni (2001) also predicted that an additional 21 percent of currently cultivated land would reach critical soil depth over the coming 15–47 years. Similar problems of high rates of land degradation and negative productivity impacts have been observed in the Ginchi watershed near Holetta in the Oromia region (Okumu et al. 2002); Andit Tid watershed in north Shewa (Shiferaw and Holden 2001); and other high-potential locations in Ethiopia (see Desta et al. 2001 and Tefera et al. 2002).

Some of the more recent studies emphasize that soil fertility depletion is at least equal in importance to the problem of soil erosion, which was the main emphasis of the earlier studies. Though soil erosion still contributes to a decline in agricultural productivity, the reassessments by Sutcliffe (1993), Bojö and Cassells (1995), and WBISPP are fairly persuasive that the costs of erosion are probably lower than determined earlier, whereas the costs of soil nutrient depletion are more important. This finding is supported by findings from Sonneveld's (2002) empirical study and from actual production and yield data since 1985. It is also highly likely that Sutcliffe's and Bojö and Cassells' approaches to estimating costs of burning organic materials overstate those costs, since the usefulness of these organic materials as a fertilizer is probably less than assumed in many cases, given the loss of nitrogen from manure, the difficulties of applying manure on distant plots, and other issues. Our sense is that the on-site costs of these types of land degradation may still be less than Bojö and Cassells estimate. Nevertheless, other aspects of land degradation have not been taken into account by any of the studies, particularly off-site costs. It is important that such impacts be considered in designing policies and programs to address land degradation and sustainable land management in Ethiopia.

The key gap is the absence of a full cost-benefit analysis of feasible options to reduce land degradation and improve productivity. Estimating the costs of land degradation, no matter how well done, will only take us a little way towards deciding what to do about it. Decision makers need to know what actions can be taken that are socially profitable. Obtaining that information requires an investigation of off-site effects where they are likely to be important, as well as on-site costs and benefits of land management options. Such off-site effects could be quite important in particular watersheds, especially where water resource development is taking place.

Annex 1: Definitions of Measures of Economic Losses

Bojö and Cassells (1995:12–13) use the following definitions of the three measures of economic losses they report in their work.

1. ***Gross annual immediate loss (GAIL):*** This measure is defined as the loss of gross agricultural output in a single year due to land degradation in the same period of time. The comparator is generally gross agricultural output in the absence of land degradation. The GAIL concept is "gross" because it does not account for (a) the cost of combating land degradation or (b) any cost reductions related to lower production.

2. ***Gross discounted future loss (GDFL):*** Because the loss of soil particles is irreversible, the loss in any one year will affect production in all future years. In other words, this concept captures a loss of natural capital and is relevant for any discussion on adjusting the System of National Accounts to better reflect environmental damage. The value of future costs is translated to a current value using a discount rate (*r*). For an infinite time horizon, the GDFL = GAIL. This concept does not apply to nutrient losses.

3. ***Gross discounted cumulative loss (GDCL):*** This concept captures the fact that land degradation is a cumulative process, in which each year's erosion and nutrient removal is followed by another, adding layers of cost. This concept also applies to nutrient breaches, as there will be a stream of GAILs, most likely increasing because of population growth and the mounting scarcity of fuelwood.

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