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Cost of Land Degradation in Ethiopia:

A Critical Review of Past Studies

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1. Introduction

Over the last few decades, there have been several efforts to evaluate the cost of land degradation in Ethiopia. These studies have reached widely varying conclusions concerning the nature, extent and economic cost of the land degradation problem. The diversity in methodological approaches and underlying assumptions used by these studies, contributes to this diversity of conclusions. This, together with the fact that the costs reported by different studies are not always reported in a manner that allows comparisons across them to be made, limits the ability to draw clear implications for policy and program decisions related to sustainable land management.

To address this problem, this study will review the past studies of the cost of land degradation in Ethiopia, assess the major methodological and conceptual issues and problems existing in the different approaches, compare the findings across these studies considering the relative merits of the different approaches, and draw implications for policies and programs, as well as for future research related to land management in Ethiopia.

The major objectives of this review are, therefore, the following:

- To review the major methodological and conceptual issues involved in estimating the costs of land degradation;
- To critically review the methods, assumptions and drawbacks of past estimates of the cost of land degradation in Ethiopia;
- To compare the estimates across the available studies and compare those with other estimates for sub-Saharan Africa and other developing countries.

The rest of the paper is organized as follows. In section 2, we present major theoretical and conceptual issues related to estimating the cost of land degradation. In section 3, past studies estimating the cost of land degradation in Ethiopia are critically reviewed. In section 4 we compare the past estimates of land degradation in Ethiopia, considering the reliability of the findings and how these compare to other estimates of costs of land degradation in other countries of sub-Saharan Africa. In section 5, we draw conclusions and implications.

2. Methodological and conceptual issues in cost estimation of land degradation

Before entering into the assessment of previous studies of cost of land degradation in Ethiopia, there is a need to clarify the major conceptual and methodological issues that are raised by attempts to estimate the cost of land degradation.

2.1. Definitional problems/confusions

It is important to define and distinguish related concepts such as land degradation, soil degradation, and soil erosion, as these are sometimes (incorrectly) used interchangeably. Land degradation is a broad term, reflecting the fact that land itself is a broad term, including more than just the soil. The U.N. Convention to Combat Desertification defines land as "the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system", and land degradation as "reduction or loss . . . of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from . . . processes . . . such as (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, biological or economic properties of the soil; and (iii) long-term loss of natural vegetation" (Pagiola 1999).

Soil degradation is a narrower term for declining soil quality, encompassing the deterioration in physical, chemical and biological attributes of the soil (Enters 1998). Soil erosion is a particular physical process that causes land and soil degradation, and refers to the wearing away of the land surface by water and/or wind as well as to the reduction in soil productivity due to physical loss of topsoil, reduction in rooting depth, removal of plant nutrients, and loss of water (Ibid.). Other forms of soil degradation include other types of physical degradation, such as compaction, surface sealing and crusting, waterlogging and aridification; chemical degradation, including depletion of soil nutrients, acidification, salinization, and pollution; and biological degradation, including loss of soil organic matter (which also affects physical and chemical properties of the soil), flora and fauna populations or species in the soil (e.g., earthworms, termites and microorganisms) (Scherr 1999).

Land degradation is a complex phenomenon influenced by natural and socio-economic factors. Most cost estimates of land degradation do not distinguish between soil erosion, soil degradation and land degradation in their analyses. In many economic analyses, there is a tendency to attribute soil fertility decline only to soil erosion. Erosion is treated as the sole contributing factor to soil/land degradation and yield declines, as the impacts of nutrient depletion on crop yields are underestimated or completely neglected. In fact, soil erosion could be a major component of on-site costs, particularly on steeper slopes (Kerr and Pender, 2005). However, in many developing countries, especially in Africa, soil nutrient mining is also often identified as a very serious problem (Stoorvogel, et al. 1993; Bojö and Cassells, 1995). Research on soil nutrient balances in Africa highlights that besides erosion, soil fertility is also reduced by the removal of harvested crop parts and residues, leaching and volatilization/denitrification losses (Stoorvogel et al, 1993; Smaling et al, 1996). The fact that different studies estimate different components of land degradation makes comparison of cost estimates across studies a difficult task.

Understanding the contribution of each component of land 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.

2.2. Estimating soil erosion rates

Soil erosion is a complex phenomenon influenced by many natural and socio-economic factors. Soil erosion is a flow concept and is measured as a rate; e.g., x tonnes/ha/year. Soil erosion includes a range of phenomena such as sheet erosion (the removal of thin layers of topsoil from an eroded site), rill and gully erosion (the formation of small incised rills or large gullies on a slope), mass wasting (the structural failure of part of a hillside as in the case of a landslide); wind erosion, tunnel erosion (caused by percolation of groundwater through a porous mantle) and fluvial (stream bank) erosion (Wright and Adamseged 1984). Often gully erosion and mass-wasting contribute more to erosion than surface erosion phenomena such as sheet erosion in uplands and highlands, even without human influences (El-Swaify, 1997).

The Universal Soil Loss Equation (USLE) is a widely applied methodology used to estimate sheet and rill erosion rates. The USLE, which was first developed by Wischmeier and Smith (1978), is given by the following equation:

$$E = f(C, S, T, L)$$

where

E is the average annual erosion

C is the climatic factor (rainfall, wind, etc.)

S is the soil factor (soil erodibility of a specific soil type)

T is the topography factor (slope and length of the field)

L is the land utilisation factor (cropping management and erosion control practices).

Due to its relatively modest data demands and transparent model structure, the USLE remains the most popular tool for estimating water erosion (sheet and rill erosion) rates. However, although it is designed to predict long term average annual soil erosion for alternative combinations of crop systems and management practices in association with specified soil types, rainfall patterns, and topography; it does not predict soil deposition or sediment yield from gully or channel erosion. Furthermore, most of the USLE data are from the croplands. Extension of the USLE to range lands, forest lands or other sites without an extensive data base is highly controversial (Stocking, 1995). Furthermore, since it was developed for soils and conditions in the United States, we should expect errors if applied in the tropics (Ibid).

To estimate the economic significance of land degradation, it is necessary to develop models that link the soil erosion rates and other aspects of land degradation to the changes in crop production and farming systems. The most common approaches in the literature are discussed in the next section.

2.3. Approaches to measuring the on-site costs of soil degradation

Two methods are most commonly used to estimate the financial on-site costs of soil erosion:

- Replacement cost approach
- Productivity change approach

Other methods of valuation include contingent valuation and hedonic pricing (Enters 1998). Contingent valuation involves asking individuals about their willingness to accept compensation for the negative effects of erosion or their willingness to pay for the benefits of conservation. This approach can also be used to assess off-site costs of land degradation. We are not aware of any studies using this approach to assessing the costs of land degradation in Ethiopia, although such an approach could be used.

Hedonic pricing uses land prices to assess the economic value of land degradation. This approach depends upon well functioning land markets, which is a doubtful proposition in Ethiopia since land sales are prohibited. It is possible that impacts of land degradation are also reflected to some extent in land rental markets, though probably only to a very limited extent, since most rental contracts in Ethiopia are short-term in nature. For this review we therefore consider only the replacement cost and productivity change approaches in more detail.

2.3.1 The replacement cost approach

The replacement cost approach calculates the costs that would have to be incurred in order to replace a damaged asset (soil); e.g., the annual marginal costs of fertilizer applications to compensate for the loss of soil nutrients due to erosion. The replacement cost approach is appealing but can be misleading for two basic reasons: (i), the replacement good (in many cases fertilizer) is not a perfect substitute for the original good (in this case soil depth and fertility), and (ii) the replacement costs does not necessarily reflect the opportunity costs of the good being degraded (i.e., lost benefits of soil depth and fertility due to land degradation). Errors caused by the first reason will tend to lead to underestimation of the cost of land degradation, while errors due to the second reason will often tend to overestimate the cost. More specifically:

- Soil erosion does not only affect nutrient status of the soil but also its organic matter content and its physical structure.
- Soil nutrients may not be the most limiting factor in crop production (Bojö, 1996)
- Fertilizer applications are not necessarily the most cost effective option available for farmers for maintaining yields; in extreme cases, e.g., on deep and fertile soils, farmers may not even experience any yield decline (Stocking, 1995).
- The replacement cost is a measure of the cost of avoiding or mitigating land degradation and not a measure of the cost of allowing land degradation (which is the same as the benefit of avoiding land degradation). The replacement cost may be much larger than the benefit of avoiding land degradation, which is one reason why farmers may allow their land to degrade. For example, the costs of replacing the lost nutrients associated with soil erosion may be much higher than farmers would be willing to invest to mitigate this loss.

In summary, the replacement cost approach is simple to apply when nutrient loss data are available (Bojö, 1996). However, given the above weaknesses it is an imperfect proxy.

2.3.2. The change of productivity approach

Under this approach, the value of land degradation damage equals the value of the lost crop production valued at market prices (with future losses discounted by market interest rates). As a physical measurement, it relies on projected crop yields with and without soil erosion. Crop yields are then multiplied by the unit price of the crops.

The change in productivity approach is logical and is straightforward to apply, but requires substantial information regarding production and degradation processes, and how the specific nature of land degradation affects production. However the methodology has some inherent problems too. Enters (1998) noted the following weaknesses of this approach.

- Crop production is highly variable and depends, especially in rainfed production, on the reliability of the onset of the rain. Thus yield decline is not always ascribable to land degradation. The impacts of land degradation would therefore need to be applied either on an assumed average situation or, preferably, on distributions of climatic and other key factors affecting production.
- Under this approach, yield declines are compared with hypothetical benchmarks of undegraded soils. The question of what production would be in the "without land degradation" case is not obvious in most studies.
- The possible existence of irreversibility means that a higher cost should be charged against irreversible land degradation than just the estimated relation between yield decline and degradation. This is because the natural capital stock may have an option value that is lost when irreversible damages occur in the presence of uncertainty about the future value of that stock (Arrow and Fisher 1974). That option value is not taken into account by conventional cost-benefit approaches (Ibid.; Dixit and Pindyck 1994).[1]

[1] To the extent that the loss in natural capital results in reduced future productivity, this loss will be reflected in the gross discounted future loss measure (see Appendix 1). However, there may be a loss in option value resulting from land degradation even if the expected impact on future productivity is zero. For example, suppose that soil erosion reduces soil depth in a site from 2 to 1 meter, and that this loss is expected to have no impact on future productivity under normal conditions. However, the buffer offered by additional soil depth may prevent future losses under unforeseen adverse future conditions (e.g., future droughts or landslides). This loss in buffering capacity against unforeseen changes in future conditions represents the loss in option value due

In summary, the change of productivity approach is more appealing than the replacement cost approach for valuing on-site costs of land degradation, although it also has drawbacks as noted above. In addition, a number of analysts have noted that the simulation models based on the replacement and change of productivity approaches do not represent fundamental hydrological and erosion processes and their results are therefore inaccurate (Enters, 1998). Physical soil loss is only a rough proxy for soil fertility decline (Bishop, 1995) and it is difficult to attribute crop yields to differences in past erosion (Olson et al, 1994). In fact as Pagiola (1992) notes, even high erosion rates may affect crop yields only marginally on deep soils with favourable subsoil characteristics. Soil erosion can take many years to affect crop productivity. There is rarely a one-to-one relationship between the amount of soil lost and the effects on yields. While the displacement of soil is irreversible, the effects of erosion on productive capacity depend on the depth and quality of soil remaining and not on soil lost (Scherr and Yadav, 1996). In addition, in semi-arid regions, reductions in moisture-retention capacity due to erosion are often a more significant contributor to yield decline than the loss of soil per se (Pagiola, 1992; Pender and Kerr; 1998, Kerr and Pender, 2005). Furthermore, most analysts consider “moved soil” as “lost soil” even though much of it may be deposited on other agricultural land, trapped by indigenous technologies such as soil harvesting structures or trapped and redistributed to fields as an inexpensive source of fertilizer (Lutz et al, 1994; Stocking, 1995; Kerr and Pender, 2005). Finally, it should be remembered that the short term impacts of land degradation on agricultural productivity can often be partly or fully compensated by use of other productive inputs such as labour, capital, and fertilizers. When there is such adaptive behaviour, a narrow view of the impacts of land degradation

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to irreversible land degradation. If land degradation is reversible (with no sunk cost), this option value does not exist, because the less degraded soil condition could be readily restored when its value is recognized.

may underestimate the impacts of land degradation. The focus should therefore be on the long-term impacts on the profitability of agriculture (Dejene, 2003).

Cost-Benefit Analysis (CBA)

CBA of land degradation and of sustainable land management interventions relies on estimates obtained using the above approaches to impute costs to land degradation or benefits to soil conservation. Deducting the stream of net income earned from land degrading practices from the stream of net income from a soil conserving practice determines the “incremental” value which in this case is the cost of erosion (Eaton, 1996). This is the very essence of a CBA. The time aspect is crucial when soil conserving practices are compared with exploitative practices. In terms of crop productivity, practices usually become more distinguishable only in the future. In other words, yields are expected to differ more significantly in the future than at present or after a period of only a few years. Absolute costs and benefits are expected to differ between these two scenarios and they may also occur at different times.

The full CBA framework is a comprehensive approach to estimate the cost of land degradation. It should take into account all of the current and future costs/benefits, technological progress and associated costs. Furthermore, off-site costs could be explicitly incorporated into the analysis.

Since CBA depends on methods to estimate such as those discussed above to estimate costs of land degradation or benefits or conservation, it faces the same weaknesses already discussed. CBA is also sensitive to the discount rate and the time horizon used for analysis. The social rate of discount and time horizon is a much debated issue (Ekbom, 1992). A “weak spot” in many cost-benefit studies is the rationale for the choice of discount rate and the time horizon (Bojö, 1986a; Ekbom, 1992). As the selected interest rate and time horizon obviously influences the results of the CBA, they need careful consideration. In many studies, the empirical basis for the rates used is at best weak; in most cases no explanations are provided (Bojö, 1986b). Studies also often fail to provide any rationale for their choice of time horizon, which ranges from six to 100 years (Enters, 1998).

Apart from the issue of choosing an appropriate discount rate and time horizon, many attempts to use CBA are also frustrated by imperfect information as this method demands huge and detailed datasets for its precise application.

Another issue often not addressed in a standard CBA (especially financial CBA) is the use of shadow prices that take risk and imperfect markets into consideration. This is particularly important when one computes economic viz-a-viz financial costs of land degradation.

2.4. The problem of aggregating (scaling up) the cost of land degradation

On-site costs of land degradation can be estimated at various hierarchical scales, such as the cropping/farming system, village/catchment, regional or national scales. Theoretically, the valuation methods discussed above can be used at any level. But practically it is not possible to estimate the cost of erosion for each individual field or farm and then aggregate to national level. Therefore, authors usually identify landscape units for which they expect the same or similar impacts. The most straightforward approach is then to add up the annual costs of soil erosion for each unit and thereby derive the total cost due to erosion nationwide (Bishop, 1995). The straightforward approach described above has a number of problems that are not immediately apparent when only aggregate figures are provided. Enters (1998) noted the following problems.

- It ignores possible price effects of differences in total agricultural production resulting from land degradation. Such price effects may be limited in many circumstances, however, because land degradation usually affects only a portion of cultivated land and may be offset by farmers' use of inputs, so that effects on total production are small. Furthermore, price impacts for tradable commodities will be limited by world market prices.
- It does not allow for a change in crop choice over time. In response to declining productivity, farmers may change to less nutrient demanding or less erosive crops.
- If originally soil loss was measured or estimated on the smallest spatial units, then aggregation will also only deal with soil loss. Adding up all the soil losses basically means that soil deposition in downstream areas is ignored. Stocking (1995) points out that net soil losses from major catchments and river systems are typically only a few percent of the gross soil losses from land in the catchment, as a result of deposition of eroded soil within the same catchment. As a result, the total cost of erosion to the national economy may be greatly overestimated if based on gross erosion rates as predicted by USLE or similar plot scale erosion estimates.
- The cost of erosion depends on economic as well as biophysical processes. Variables such as crop prices, off-farm employment opportunities, discount rates, credit availability, and farmers' perspectives affect the cost of agricultural production and erosion as much as slope, soil quality, and rainfall intensity. These variables are usually not considered in aggregation.

2.5. Off-site costs of land degradation: neglected impacts

Once soil and excessive runoff leave the boundary of individual farms they cause off-site or off-farm impacts and result in costs or benefits that are external to the farm household. Clark (1996) lists 16 off-site costs of soil erosion, of which the most important are likely in-stream problems of water quality and quantity, sedimentation effects on reservoirs, the degradation of potable water, a decrease in the availability of irrigation water, increased dredging or siltation, accelerated runoff leading to localized flooding , reduced hydrological cycling and recharge of ground water. Such costs are usually not internalized by upstream land users and affect downstream resource users. 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. Pagiola (1999) identifies potential impacts of land degradation on climate change (by affecting soil organic carbon sinks as well as above ground carbon stocks in the form of vegetation, and effects on albedo (reflectivity) of the earth's surface); biodiversity (both above and below ground); and international waters as potentially important international impacts of land degradation (though little research has established the magnitude of such impacts).

It is important to recognize that not all external impacts of land degradation are necessarily negative. As mentioned above, soil erosion may lead to beneficial inflows of soil and plant nutrients to farmers downstream (e.g., farmers in the Nile delta have long benefited from erosion occurring in Ethiopia and elsewhere in the Nile Basin). Increased runoff of water caused by land degradation in uplands may also be captured and used by farmers or other water users downstream. We know of no studies that have attempted to quantify such positive externalities due to land degradation, however.

So far, most studies estimating the costs of land degradation have concentrated on the on-site impacts; the analysis of off-site effects, despite often being recommended, has been rare, and is usually conducted only in qualitative terms, due to the difficulties of measuring such impacts.

3. Review of past estimates on on-site costs of land degradation in Ethiopia: Basic assumptions, major findings and drawbacks

3.1. Scope of the review

There are a number of studies that estimate the on-site costs of land degradation in Ethiopia. The following are the main works that we have reviewed:

1) The Ethiopian Highlands Reclamation Study (EHRS) (FAO 1986a, 1986b);

2) The Soil Conservation Research Project (SCRP) (Hurni, 1988);

3) The National Conservation Strategy Secretariat (NCSS) (Sutcliffe 1993);

4) The World Bank's reassessment (Bojö and Cassells 1995); and

5) Estimates by Sonneveld, 2002.

6) The Woody Biomass Inventory and Strategic Planning Project (WBISPP) (WBISPP 2001a, 2001b, 2001c, 2002, 2003a, 2003b, 2004a, 2004b)

The selection of the studies reviewed was mainly based on national or regional level coverage from available sources.

Most of the studies reviewed focus on the Ethiopian highlands (EHRS, SCRP, NCSS, Bojö and Cassells), which include areas over 1500 meters above sea level but including associated valleys. This appears to be restrictive as the Ethiopian highlands cover only about 44 percent of the country's total area. However, it may not be so restrictive when we consider the facts that about 90 percent of the human population, about two-thirds of the livestock population and well over 90 percent of the regularly cropped land are found in the Ethiopian highlands.

The studies reviewed mainly use data from before 1993, and national level data used in these studies include Eritrea, which was part of Ethiopia until 1993.

We may also note that the review focuses on on-site costs/impacts although we make reference to off-site (downstream) impacts depending on the nature of the studies reviewed.

For each study reviewed in this section we present the basic assumptions and methods used to estimate the extent and costs of land degradation followed by a discussion of the key findings and drawbacks.

3.2. Review of previous studies

3.2.1. The Ethiopian Highlands Reclamation Study (EHRS)

This is perhaps the most comprehensive and detailed study addressing the issue of land degradation in Ethiopia. This review is mainly based on two volumes of reports by the EHRS (FAO 1986a, 1986b), which are based on over 20 working papers prepared as part of the EHRS. The EHRS addresses a wide range of topics but in this review we focus on the extent and costs of land degradation. Discussion of these issues in the EHRS is fairly detailed, including analysis done by (three) zones (high potential cereal (HPC), low potential cereal (LPC) and high potential perennial (HPP) zones) and also by altitudinal belt (class). In this review we focus on the country level estimates for the highlands.

A. Basic assumptions and methods

A.1 Extent of land degradation

Broad categories of soil degradation were presented, including water erosion (which includes sheet (or inter-rill) erosion, rill erosion, gully erosion, bank erosion, tunnel erosion and land slides), wind erosion, chemical degradation, physical degradation and biological degradation. It is noted that the severity of soil degradation depends largely on the remaining soil depth (which is affected by soil erosion) and the fertility of that soil (which is affected by all forms of biological, physical and chemical degradation) (FAO 1986a: 162).

The extent of erosion was estimated using soil depth and geomorphological maps and data compiled by the Land Use Planning and Regulatory Department (LUPRD) of the Ministry of Agriculture, together with extensive field trips. FAO (1986a) notes that the estimates of the existing erosion according to severity were done on an admittedly subjective basis.

After discussing the presence of wide variation in estimates of soil formation in situ[2], FAO (1986a: 181) reported that soil formation rates were calculated for the highlands from data on temperature, rainfall, length of growing period, soil units, soil depth, slope gradient, land cover and use. While estimates arrived at using this method were considered to provide a reasonable indicator of relative rates of soil formation in the highlands, the estimates were tentative and the method used for estimation was still being developed in light of field verifications, although no further refinements were completed as a part of the EHRS.

[2] Three processes were identified for soil formation at a given site: 1) the re-deposition of sediment by runoff erosion from a higher site; 2) the natural weathering of rock beneath the soil; and 3) the formation of soil at the surface by decaying organic and inorganic materials caused by both natural processes and by cropping (FAO 1986a: 181).

Both geological erosion and accelerated (human-induced) erosion contribute to current rates of erosion. After quoting various estimates of soil loss for Ethiopia, it is noted that the variation is indicative of conceptual, methodological and statistical difficulties inherent in making such estimates and the variability of such estimates over time and space. Though details are not provided,[3] estimates of gross soil erosion rates are based on an FAO method derived from the Universal Soil Loss Equation (USLE). FAO (1986a: 182) notes that while the application of the method provides reasonable estimates of relative rates of erosion in the highlands, it probably overestimates rates of erosion in absolute terms.

It was also assumed that 80 percent of the total gross soil loss was from croplands while most of the remaining 20 percent was from overgrazed grasslands and a little from wastelands and other lands. This assumption was based on records of SCRP which show much lower soil losses from grass plots, allowing for overgrazing of some grasslands and taking into account the grasslands area of the highlands (FAO 1986a: 182). Ninety percent of the soil eroded was assumed to be redeposited evenly across land use types.

Projections of soil depth in 2010 were made based on the assumption that estimated rates of erosion would continue from 1985 to 2010, although as noted in FAO (1986a), this is unlikely since population growth and the processes of erosion are likely to accelerate rates of erosion.

Sheet and rill erosion were estimated to be by far the most important types of accelerated erosion in all zones and altitudinal belts. In terms of areas affected and soil irretrievably lost,

[3] It is indicated in the FAO (1986a) report that the method is described in LUPRD/UNDP/FAO (1984) which we have not been able to locate.

wind erosion and all other forms of erosion combined were considered to be less significant than the sheet and rill erosion caused by water (FAO 1986a: 166-170).

FAO (1986a) also noted that biological degradation adversely interacts with and aggravates accelerated soil erosion, as it was considered to be both widespread and severe in the highlands. It was also noted that obvious indicators of biological degradation include removal of crop residues and dung from fields, overgrazing and deforestation (FAO 1986a: 170). Physical degradation of soils was also considered as being commonly associated with biological degradation and water erosion in the highlands, while chemical degradation was said to be rarely found in actively eroding soils and more common in stable soils under more favorable conditions of high and long rainfall (FAO 1986a: 170-171). As a conclusion of the discussion of biological, physical and chemical degradation, FAO (1986) concluded that the consensus from the EHRS and other informed opinion "is that sheet and rill erosion and inter-related biological degradation are by far the most important forms of soil degradation in the Highlands, both in their area coverage and in their impact on reducing soil productivity" (FAO 1986a: 171) Estimated rates of soil loss were thus based only on the impact of water erosion.

A.2 Costs of land degradation

FAO (1986a) tried to assess the magnitude of the degradation problem in social and economic terms. Referring to the conclusion in 1981 of a USA National Soil Erosion/Soil Productivity Research Planning Committee that "erosion reduces productivity first and foremost through loss of plant-available soil water capacity", FAO noted the need to consider the relation between erosion induced yield reductions and remaining soil depth. However, the difficulty and even impossibility of precise quantification of many of the effects of degradation due to conceptual problems and lack of data was noted. FAO (1986a) noted the difficulty of estimating these in the Ethiopian highlands as almost all of the experimental studies of soil erosion – production relationships were conducted in the USA and Australia, these studies were field pilot trials and hence the results are site-specific. The analysis of costs of land degradation was therefore based on guesstimates and sensitivity analysis was also conducted to examine the sensitivity of results to alternative assumptions.

After a review of international evidence on estimates of yield losses due to soil erosion that mainly focused on temperate regions with soils on slopes of 10 percent or less, it was noted that yield declines tend to be higher in the tropics. Slopes in much of the cropland in the Ethiopian highlands are much steeper than those reviewed and small seed cereals require finer seedbeds and hence more ploughings than maize. These arguments and estimates of soil loss discussed above were used to estimate annual yield reductions by FAO (1986a: 196). No formal model was presented for yield reduction estimates; rather, the estimates were based on "guesstimates" using the international evidence reviewed as a starting point.

Downstream effects were also discussed but the conclusion was that it is difficult to quantify many of these effects due to lack of data on sedimentation and the limited time and resources available. The importance of the effects was, however, noted such that there are some areas of the highlands where downstream costs of degradation may even be larger than on-farm costs.

Tentative on-site monetary costs of degradation at the national and farm levels were also estimated. Methodological weaknesses were noted which arise from weak data and limited understanding of relations between soil losses and yield reductions and the difficulties in projecting soil losses. The effects of different assumptions and guesstimates were considered in a sensitivity analysis. Estimates of reductions in crop and grass production were derived for the 25-year period (1985-2010) classified by three zones and three altitudinal classes. Four types of costs were specified, viz., lost cropland, lower crop yield, lost grazing land, and lower grass yield. These costs were compared to a situation where there is no soil erosion. We should also note that 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 the computation of present value of costs of degradation (FAO 1986a: 201).[4] The sensitivity of the cost estimates was also analyzed by assuming lower rates of soil erosion.

FAO (1986a: 184) notes that while soil erosion rates are likely to accelerate in the absence of conservation measures,[5] the analysis uses the conservative assumption that rates of soil erosion would be constant over time. No change in agricultural productivity is also assumed which may be a conservative assumption if baseline agricultural productivity is expected to rise over time so that yield reductions due to degradation become more than assumed. Prices paid by the Agricultural Marketing Corporation (AMC) were used, which would underestimate costs as these were between 20 and 30 percent lower than market prices at the time of the study.

[4] 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 1986a: 201). We may also note that the FAO report (FAO 1986a) discusses the issue of whether one should discount future costs of soil erosion as it would have negative implications for the future generation of Ethiopians.

[5] Arguments to support this include reductions in soil productivity result in thinner vegetative cover, giving rise to greater erosion; progressive selective removal of the lighter particles and organic materials from the soil by erosion would make soil increasingly more erodible as it leaves behind the coarser silt and sand; most sub-soils are already heavier and inherently less permeable than top soils because of their structure and texture so that run-off increases. In addition to these technical reasons FAO (1986) also mentioned population growth as a contributor to increased erosion. However, it is also noted that only in some of the already most severely degraded areas of the highlands are erosion rates likely to decline as the amount of soil left to erode is less (FAO 1986a: 184).

While downstream costs and most social costs were not included, estimates of the number of persons affected and some social costs were provided (FAO 1986a: 203). FAO (1986a: 198) argues that within Ethiopia any farming benefits accrued from deposition of sediment are insignificant and short-lived.[6]

B. Major findings

B.1 Extent of land degradation

Based on the estimates of the severity and extent of erosion in the mid-1980s, FAO (1986a: 166-169) concludes that about half (about 27 million hectares) of the highlands' land area was "significantly eroded", and over one-fourth (14 million hectares) was "seriously eroded". It is also concluded that over 2 million hectares of farm lands have reached the "point of no return" in the sense that they are unlikely to sustain economic crop production in the future. While the other half of the highlands was estimated to be without significant accelerated erosion, over half of this was considered to be at future risk due to the likelihood that cropping will spread in this area and the inherent erodible nature of the soils. Only about 10 million hectares of land (which is about 20 percent of the highland area) was considered to be "fairly free from the risks of serious accelerated erosion".

Annual re-deposition of soil in the lower lying highland areas was estimated to be about 90 percent of the total soil erosion (or about 1700 million tons of soil). Assuming this is distributed evenly in the highlands this is equivalent to about 35 tons of soil per hectare. Soil

[6] FAO (1986a: 198) indicates that in general the deposit of sediments may have both positive and negative effects. While much land in Egypt might never have been developed if it were not for the deposits coming from the Ethiopian highlands, the effect on farm benefits in Ethiopia is insignificant and short-lived. Top soil sediment is sooner or later covered by less fertile sub-soil sediment, and almost always the deposition of sediment leads to a reduction in the permeability of soil whereon it is deposited, as the fine particles settle into the water-conducting pores of the soil profile. Although only as low as ten percent of the soil may be totally lost, these fine particles are probably the most fertile and valuable part. Sedimentation can also damage vegetation.

formation in higher areas is, however, confined to in situ formation. The soil formation rate in situ was estimated to be from 2 to 22 tons/ha/year for the highlands, which was considerably higher than estimates reviewed for other countries (FAO 1986a: 181).

After noting data and methodological limitations in the estimation of soil erosion, estimates from LUPRD data show that total annual erosion in the highlands is about 1900 million tons of soil. As indicated above the loss from croplands is assumed to be 80 percent of the total estimated gross soil loss. This would imply that average annual gross loss from cropland was 130 tons per hectare while the average annual loss for all land in the highlands was estimated at 35 tons per hectare.

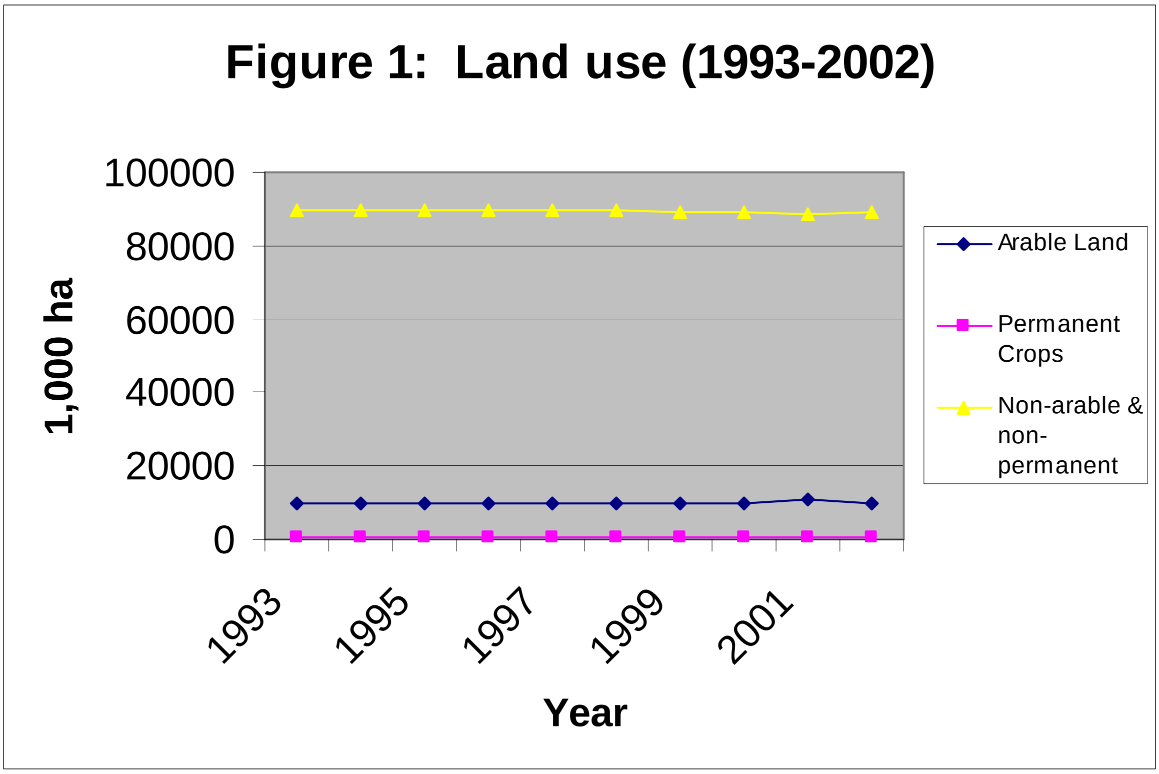
On the assumption that 90 percent of the eroded soil was re-deposited evenly per hectare, net soil losses from cropland were estimated to be about 100 tons per hectare leading to a net cropland soil loss of about 1100 million tons per annum from the highlands.[7] While most of this is deposited on grassland and forestland, the part that is carried into rivers is lost forever from highland cropping. FAO (1986a) noted that these estimates of erosion rates appear high compared with estimates for other countries. A comparison was also made with other estimates such as those by SCRP for Ethiopia, and FAO concluded that the estimated erosion rates in the EHRS could be overestimated, but probably not by more than 30 percent.[8]

Assuming no change in rates of erosion, estimates of soil depth for 2010 indicate that about 100,000 km^2 (or about 18 percent of the total area of the highlands) would be bare rock or

[7] While the rate of soil erosion is very high on cropland compared to other land uses, the assumption that soil is re-deposited evenly in the highlands and concentration of cropland at higher elevations appear to be the main reasons for the relatively smaller reduction in soil loss due to re-deposition.

[8] FAO (1986a: 183) concluded that “such comparisons suggest that the overestimation implicit in the method used is probably not more than 30 percent. Thus, even if the calculated erosion rates are reduced by 30 percent they would still be high … in comparison to rates calculated for other countries. This reflects the fact that most cultivation in the Highlands is on slopes which are very steep …in comparison to slopes … on croplands in countries for which such calculations have been made … and that cultivation in the Highlands may involve up to six ploughings, some at angles to contours, and leave the ground with very little cover during periods of very erosive rain.”

have less than 10 cm soil depth (11 percent) by 2010 compared to 4 percent under these categories in 1985. FAO (1986a: 190) concludes that on top of the 20,000 km^2 of land which is not capable of sustaining arable cropping in the mid-1980s, an additional 76,000 km^2 is likely to be similarly degraded by 2010. This claim seems to contrast with actual land use trends, which shows not much change in arable or permanent crop lands in Ethiopia since the early 1990's (Figure 1). Of course, the validity of these aggregate land use figures may be suspect[9], and they may mask important changes between or within land use categories, such as expansion of arable land into marginal areas while formerly cropped land is abandoned due to land degradation.



Source: FAOSTAT, 2005

[9] For example, the FAOSTAT (2005) figures for permanent pasture area (part of non-arable and non-permanent crop area) are implausibly given as exactly 20 million ha in every year, while forest area and other land uses were not estimated after 1994. Estimates of cropped area may be more reliable, since they may be based on agricultural surveys or crop area reports from local Bureau of Agriculture officials, although the source of such estimates are not specified in the FAOSTAT database. Unfortunately, other national level estimates of land use changes for Ethiopia are not readily available.

Several studies using remote sensing information at a micro scale have found large changes in land use in different parts of Ethiopia during the past several decades (Kebrom Tekle and Hedlund 2000; Reid, et al. 2000; Gete Zeleke and Hurni 2001; Belay Tegene 2002; Muluneh Woldetsadik 2003; Tesfaye Demissie, et al. 2004; Dwivedi, et al. 2005). Most of these studies find that cropland has expanded, usually at the expense of forests or grazing area, although there are exceptions in different places and times. For example, Reid, et al. (2000) found that cropland area declined between 1973 and 1987 in the Ghibe Valley region in southwestern Ethiopia due to drought and other factors, though it expanded between 1957 and 1973 and even more rapidly between 1987 and 1993. In the Dembecha area of Gojjam in northwestern Ethiopia, Gete Zeleke and Hurni (2001) found that cropland area expanded from 39% to 70% of the study area between 1957 and 1982, but only increased to 77% between 1982 and 1995, because of limited remaining area available suitable for expansion. Belay Tegene (2002) found a similar slowing of cropland expansion after 1986 in a catchment in South Wello, northern Ethiopia. In west Gurageland, Muluneh Woldetsadik (2003) found that tree density increased while the area of cropland increased. In the Awash River basin in eastern Ethiopia, Tesfaye Demissie, et al. (2004) found major cropland expansion and deforestation between 1965 and 1984, but the deforestation trend reversed between 1984 and 1996 due to a reforestation program. In a site in Gamo Gofa, Dwivedi, et al. (2005) found a rapid increase in cropland (22%) and shrubland/grassland (31%) between 1994 and 1997, both replacing barren land as a result of soil and water conservation measures. These studies highlight the diversity of situations concerning land use change and land degradation in Ethiopia, and the risks of relying on available macro level studies to draw conclusions.

B.2 Costs of land degradation:

Based on assumptions and methods discussed above, FAO (1986a) presents estimates of annual soil losses and the corresponding yield reductions in the highlands as a share of 1985 levels for crops and grass. The results indicate that the predicted average annual yield decline for crops and grass in the highlands compared to the 1985 level were 2.2 percent and 0.6 percent respectively. Sensitivity analysis was also conducted for “low”and “high” scenarios and the results suggest that average annual yield decline for crops and grass were 0.6 and 0.3 percent in the “low” scenario respectively. The corresponding figures for the “high” scenario were 3.4 and 1.1 percent respectively (FAO 1986a: 196, Table 7.1).

Reduction in national grain production due to soil erosion was estimated at about 2 percent per annum. The equivalent in terms of cereal production lost in the early 1980s was over 120,000 tons per annum, losses which are expected to increase substantially over time (FAO 1986a: 201).

The present value of costs of degradation over the 25-year period after the mid-1980s was estimated at EB 4,200 million which is equivalent to an average annual reduction of over 2 percent of agricultural GDP in 1982/83.

In 2010 estimates show that about 100,000 km^2 of the highlands would have a soil depth of 10 cm or lower. Assuming an even distribution of the rural population over the whole land area, which implied that in 2010 about 10 million persons would have to derive their food and income from sources other than cropping of their own lands. FAO (1986a: 204) notes that “if present trends continue, it is likely that nature will impose its own socio-ecological checks by increasingly frequent and severe famine.”

C. Drawbacks

C.1. Extent of land degradation

It is admitted in FAO (1986a: 182) that the data used for estimation of erosion rates in the highlands is very limited and necessarily site-specific and that limited use is made of remote sensing techniques. Data used by the LUPRD with the assistance of a GOE/FAO/UNDP project for calculation of erosion rates for the highland areas is at the scale of 1:2,000,000 and a USLE-type of method is used (FAO 1986a: 182). FAO also admitted that the erosion rates may well be overestimated, as noted above due to poor quality data. Estimates of soil loss and crop land lost may have been overestimates for the following additional reasons: 1) It appears that EHRS extended the definition of "cropland" to an additional 21.1 million hectares of "open and wooded grassland" which increased the figure for cropland soil losses; and 2) increase in non-cultivable areas was applied not just to cropland but to all land in the highlands which contributes to overestimation of the cropland lost. On the other hand, the costs of forms of land degradation other than water erosion were not explicitly estimated, which underestimates the estimates of the extent of land degradation. Subsequent studies (discussed below) address both of these issues.

C.2. Costs of land degradation:

Estimates of effects of erosion on yield are only guesstimates without any formal model. Exclusion of forms of land degradation other than sheet and rill erosion may contribute to the underestimation of the costs of land degradation, as would some other assumptions such as use of crop prices that were lower than market prices. On the other hand, the extent of reduction in yield due to erosion depends on soil depth. It appears that this was not taken into account in the estimation of costs, which may overstate the costs of erosion. Factors that contribute to overestimation of soil loss estimates discussed about would also have implications for crop loss estimates.

3.2.2. The Soil Conservation Research Project (SCRP)

SCRP[10] was a project with the mandate to conduct research on land degradation in Ethiopia. It was part of the Ministry of Agriculture and was implemented in collaboration with Berne University, Switzerland (Hurni 1988). Hurni (1988) noted that it is only since 1981 with the inception of SCRP that scientific approaches to soil conservation problems in Ethiopia were systematically and continuously implemented. The research program was conducted at three levels (Bojö and Cassells 1995):

1. a national level exploratory survey on rainfall erosivity;
2. regional- and district-level data collection on land use;
3. catchment and plot-level collection of soil conservation data.

We review the work by Hurni (1988) which estimated soil loss in Ethiopia as part of SCRP's efforts.

A. Basic assumptions and methods

As did the EHRS, Hurni (1988) assumed that soil erosion by water must be considered the most important of all land degradation processes. He also assumed that soils in Ethiopia were originally more than 50 cm deep and probably had rooting depths of more than 100 cm.

Soil loss rates for different land unit classes (land cover types) were estimated using the Universal Soil Loss Equation (USLE) adapted for Ethiopian conditions. Hurni (1988) noted

[10] SCRP was funded by the Swiss Directorate for Development Cooperation and the Ethiopian Government. There were a network of eight stations (out of which two were in now independent Eritrea) measuring losses, runoff, and crop yield on experimental plots using different conservation techniques (Bojö and Cassells 1995).

that these results correlated well with test-plot measurements made by the SCRP, although, as noted previously, such estimates can greatly overstate the net impact of erosion on soil loss, because of re-deposition of soils elsewhere in the landscape.

Hurni (1988) reports gross soil losses and hence the loss figures are not net of soil re-deposition and soil formation. Soil formation was separately reported so that gross losses could be compared to soil formation, as an indicator of sustainability. Estimation of soil formation was "based on assumptions of soil regeneration as a function of geology and soils (unit and depth), slope gradient, climate (temperature, rainfall, and length of growing period), and land use" (Hurni 1988: 126). Hurni also noted that the model was not validated thoroughly with field data.

B. Main findings

Hurni (1988) reported (approximate) gross soil loss rates using land cover types classified by the Ethiopian Highlands Reclamation Study (EHRS). These gross soil loss rates are reported in Table 1. The figures in Table 1 indicate considerable variation in soil loss rates by land use type.

Table 1. Estimated gross soil loss rates by land cover type[11]

Land cover	Area(%)	Soil loss	
		t/ha/year	t/year (in millions)
Cropland	13.1	42	672
Perennial crops	1.7	8	17
Grazing and browsing land	51.0	5	312
Currently unproductive (Former cropland)	3.8	70	325
Currently uncultivable	18.7	5	114
Forests	3.6	1	4
Wood and bushland	8.1	5	49
Total country	100	12	1493

Source: Hurni (1988: 127) and Bojö and Cassells (1995: 7).

We note from Table 1 that the average gross soil loss in the country was estimated to be 12 t/ha/year and 1,493 million t/year. Note that in spite of the lower gross soil loss rates compared with those for EHRS, Hurni's estimates of total soil loss per year are not very far from those of EHRS due to the fact that the former presents estimates for the entire country. We also note that the soil loss rate is much higher for cropland than for grazing, perennial crops, forests and bushland. Thus, in spite of the fact that cropland takes only about 13 percent of the total area of the country it contributes to about 45 percent of the total estimated soil loss. This has its own implications for agricultural expansion leading to increased share

[11] Note that some of the land cover types reported in Bojö and Cassells (1995) quoting the same work by Hurni (1988) are different and they note that these are revised based on personal communication with Hurni on June 15 and 16, 1994. A major difference is that what is called 'Grazing and browsing land' in Hurni seems to have been divided into 'Grazing land' and 'Swampy land' with area shares of 47% and 4% respectively in Bojö and Cassells. Bojö and Cassells also use the term 'Former cropland' which seems to be instead of 'Currently unproductive'.

of cropland and hence increased land degradation. Hurni (1988) also reported considerable variation in soil loss rates by agro-ecological zones (dry and hot lowlands, moist middle slopes, cold and wet highlands). Estimated loss rates were the highest in cultivated slopes in the Dega highland zone (2,300-3,200 m a.s.l), where there was the highest rainfall and the most intensive cultivation while soil loss from grassland was much lower (3-10 times less than from cultivated land) (Hurni 1988: 127). While Hurni's estimates of gross soil loss are lower than those of the EHRS, it appears that Hurni's estimates are more reliable for at least two reasons: 1) they were calibrated on field measurements and a more detailed subdivision of soil texture factor is used in deriving erodibility; 2) improvements have been made in the estimates of rainfall erosivity (Krauer 1988; Bojö and Cassells 1995)..

Based on soil formation rates estimated by Hurni (1988), and using a rule of thumb on soil depth[12], Bojö and Cassells report soil formation rates of 3-7 tons per hectare per year, well below the estimated loss rates.

Bojö and Cassells (1995) also report Hurni's estimates of the productivity implications of his erosion results, which postulate a 2 percent decrease in agricultural production per year due to land degradation.[13]

[12] Hurni (1988: 127) indicates that 1 millimeter of soil depth corresponds to about 10 metric tons per hectare. Note, however, that the bulk density of Ethiopian soils varies (Bojö and Cassells: 6). It seems likely that Ethiopian soils are more dense than water, which has a density of 1.0 g/cm^3, so this estimate seems low. Stocking (1996) estimates that 1 mm of soil typically weighs about 13 tons per ha. (i.e., a bulk density of 1.3 g/cm^3).

[13] Bojö and Cassells (1995: 7) note that this appears to be based on empirical measurements from Hurni's work in 1985 in which data from 52 plot samples of barley showed an annual decline in the yield of barley on the order of 2 percent per year, based on an erosion rate of 66 tons per hectare per year. Bojö and Cassells (1995: 7) indicate that Hurni confirmed through personal communication that the yield equation is: $Y=0.38+0.032X$ (where Y=barley yield in tons and X=depth of reworkable soil in centimetres), which implies a yield reduction of 320 kilograms per 10 centimeters of soil lost and not 250 kilograms as given in Hurni (1985). With an average yield of 1,820 kilograms per hectare (X=45 centimeters), this implies a relative loss of about 1.5 percent per year, given the loss rate of 66 tons/ha.

C. Drawbacks

Only soil erosion by water was considered, as with the EHRS. Though it is the major contributor to soil erosion it would lead to an underestimation of the cost of land degradation as the latter include other forms of land degradation such as biological degradation.

The effects and implications of soil re-deposition are also not considered. Moreover, referring to Hurni's work, Bojö and Cassells (1995: 6) note that the "soil formation" concept utilized by Hurni involves three separate processes; "(1) accumulation on the surface of the soil (decomposition of organic material, deposition of material transported by water and wind), (2) soil formation within the A horizon (humus formation, root development, and decomposition), and (3) weathering of parent material (development of the B horizon)". Given the three processes above, there will be double counting if the sum of re-deposition and soil formation is deducted from gross soil loss to calculate net soil loss. Information on the three processes mentioned above is required to determine the level of this double counting. This information is, however, not available as only the total is given. Bojö and Cassells (1995) note that conceptually, this would not be a problem if all re-deposition is actually included, but the figures for "soil formation" are much lower than the figures for "re-deposition" reported for example in the EHRS. This appears counterintuitive given the first process in the definition of the soil formation concept above which should include re-deposition as part of soil formation.

3.2.3. The National Conservation Strategy Secretariat (NCSS)

This review is based on Bojö and Cassells' (1995) discussion of work by Sutcliffe (1993). Using additional data, Sutcliffe (1993) presented new estimates of the extent and impacts of on-site soil erosion and the loss of nutrients through the use of dung and residues for fuel.

A. Basic assumptions and methods

Sutcliffe looks at the impact of water erosion followed by an analysis of the impact of nutrient losses due to removal of dung and crop residues. Sutcliffe followed the following steps to derive the impact of water erosion (Bojö and Cassells 1995: 8):

1. Sutcliffe used the erosion rate estimates by Hurni (1988), which he judged to be more realistic than the higher rates estimated by EHRS.
2. Sutcliffe established the minimum required depth for cultivation of different crops and the maximum required (90 cm) beyond which erosion does not immediately affect crop cultivation. He used a soil life model developed by Stocking and Pain (1983) as the analytical framework. The future user cost of decrease in soil depth was also incorporated in his calculations.
3. Using a model developed by FAO, Sutcliffe related monthly values of rainfall, water-holding capacity, evapotranspiration, and crop water requirements to derive a Water Requirements Satisfaction Index (WRSI). The relationship between the WRSI and relative reductions in crop yield was then derived.
4. Estimates from the EHRS of crop mix, absolute yields, and areas for three altitudinal ranges and three major agro-ecological zones (HPP, HPC, and LPC), were used to project losses in crop production. Losses in crop residue production were converted to tropical livestock unit (TLU) equivalents. Estimates were made for the period 1985 to 2010 to be comparable to the EHRS.
5. 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 as a whole.

Sutcliffe then builds on a methodology developed by Newcombe (1984) to analyze the impacts of breaches in the nutrient cycle due to use of dung and residue as fuel. Using estimates of actual use of dung and residues as fuel from the Ethiopian National Energy Commission, the estimates were derived in the following three steps:

1. The amount of nitrogen (N) and phosphorus (P) lost and their impacts in terms of lost crop production were calculated;

2. The burnt crop residues were evaluated in terms of their potential value as livestock feed and converted to potential increases in TLUs, which in turn are priced.

3. The replacement value of nutrients lost, using the price of chemical fertilizers, was calculated.

B. Main findings

Estimates of soil erosion damage and nutrient breaches are given separately below. Sutcliffe's soil erosion damage estimates are presented in Table 2. Sutcliffe's estimates of crop production losses and cropland losses for 1985 were only about 7 percent and 6 percent of the respective EHRS estimates.

Table 2. Soil erosion damage estimates

Year	Estimates
Crop production losses (rounded to thousands of tons)	
1985	9
2010	332
Cropland lost (thousands of hectares)	
2010	489
Pastures lost (thousands of hectares)	
2010	5,747

Source: Adapted from Sutcliffe (1993) by Bojö and Cassells (1995: 9)

As noted above, Sutcliffe also estimated the cost of breaches in the nutrient cycle. The results show losses that are much larger than those for erosion. The 1990 losses in physical terms are estimated as (1) almost half a million tons of grain; and (2) more than 1 million TLUs. These losses are much higher than those for soil erosion in 1985 (see Table 2). The corresponding differences in monetary costs between soil erosion and nutrient losses would also be large.

Bojö and Cassells (1995: 9) report that Sutcliffe estimates total crop losses due to losses from both erosion and nutrient loss to be at about 0.5 million tons in 1985 (the base year for his calculations). When livestock losses are added, he derives a total cost of EB 581 million in 1985 which corresponds to about EB934 million in 1994.

These results imply that the cost of land degradation due to erosion is much less than suggested by previous studies. On the other hand, the cost of nutrient losses was estimated to be very large.

The following are noted by Bojö and Cassells (1995: 9) as important reasons for the differences in methodologies used and hence the results between EHRS and Sutcliffe's work: 1) Sutcliffe used Hurni's lower estimates of gross soil loss than those used by EHRS for reasons mentioned above; 2) EHRS used a loss in productivity of about 2.2 percent per annum to the entire crop production area, regardless of soil depth. As noted above Sutcliffe uses the assumption that crop losses set in only after reaching a depth of not more than 90 centimeters while still accounting for the future user cost; 3) about 21.1 million hectares of "open and wooded grassland" appears to have been included by EHRS in the definition of "cropland"; this would overstate the total soil loss estimates as there are even actual gains in topsoil cover on grazing land; and 4) the EHRS applied the percentage increase in non-cultivable areas to all land in the highlands, not only cropland which increased the estimated area of wasteland to 7.6 million hectares of "cropland" loss in the year 2010.

C. Drawbacks

Bojö and Cassells (1995: 11-12) point out a number of drawbacks of the study by Sutcliffe (1993). First, there may be an element of double counting 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 also 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 would reduce Sutcliffe's estimate downward by more than 20 percent.

Second, Bojö and Cassells (1995) note that there is probably double counting in estimation of the cost of livestock losses from burning residues instead of using them as livestock feed.

The sum of the value of flow products and services from livestock and the value of livestock as a "store of wealth" is taken as a measure of the cost. Since 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, double counting will occur since the flow values are separately accounted for. Moreover, the investment before the sale of livestock is not deducted when calculating the net value of the entire (remaining) life cycle of a livestock unit. While adjustment for these would revise the damage estimates downwards considerably, such adjustment of Sutcliffe's figures was not possible as the necessary details were not provided.

Third, Sutcliffe followed Hurni not only in using his estimates of gross soil losses but also in not adjusting for re-deposition of soil to arrive at net losses. Bojö and Cassells (1995) note also that in subsequent communications, Sutcliffe indicated that more detailed USLE calculations taking account of the likely distribution of slope and soil depth classes reduced average losses from cropland to about 20 tons per hectare per year (without any allowance for re-deposition processes). Thus water erosion losses may still be overstated in Sutcliffe's study, even though these are estimated to be much lower than in either the EHRS or Hurni's study.

Fourth, the availability to plants of removed nutrients contained in burned dung and residues may be limited. The implicit assumption appears to be that such nutrients are highly available for plant growth, in the sense that the nutrient content is a perfect substitute for commercial fertilizer. This is more likely for dung than for residues, but may not hold even for dung, depending on how it is managed.[14] Thus, the costs associated with burning dung and crop residues are probably overstated by Sutcliffe (1993).

3.2. 4. World Bank's reassessment

After a review of previous major studies on land degradation in Ethiopia, Bojö and Cassells (1995) reassessed the problem 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, viz. gross annual immediate loss (GAIL), gross discounted future loss (GDFL) and gross discounted cumulative loss (GDCL) (see Appendix 1 for definitions of these concepts). Their reassessment is reviewed below.

A. Basic assumptions and methods

A.1 Extent of land degradation

Bojö and Cassells' estimates of land degradation are mainly based on the approach followed by Sutcliffe, where both soil erosion and nutrient losses are taken into account. In cases where data is available, the drawbacks of Sutcliffe's work reviewed above were addressed by Bojö and Cassells to arrive at revised estimates. Moreover, Bojö and Cassells (1995) pay particular attention to the issue of re-deposition. They noted the importance of attempting to take into account re-deposition in spite of problems of lack of information. Based on previous work they argue that "the net rate at which the soil is lost to agriculture is lower than the gross rate of soil erosion as estimated by even the most rigorous geomorphic applications of USLE-type calculations. … Hence, there is reason to adjust previous calculations of the rate of soil loss down even further than suggested by the National Conservation Strategy Secretariat" (Bojö and Cassells 1995: 40). Thus, they argued, due to re-deposition "net soil

[14] 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).

loss to cropland is probably on the order of half or less of the gross figures used in previous analyses” (p. 12).

A.2. Costs of land degradation

Costs of soil erosion:

Using a matrix derived by Sutcliffe (1993), Bojö and Cassells (1995) related various rates of soil loss per annum with relative decline in yield. An average decline of 0.4 percent per year was obtained for all cereals as a function of soil loss. Information on distribution of soil depth was used to calculate the decline in crop yield.

The figure for yield impacts of erosion used by Bojö and Cassells is similar in order of magnitude to most estimates of yield impacts of soil erosion in several studies for other parts of the world (Wiebe 2003). For example, Crosson (1995a) estimated an annual average agricultural productivity loss of 0.4 percent globally on degraded lands between 1945 and 1990, based upon estimates from the Global Assessment of Soil Degradation (GLASOD) by Oldeman, et al. (1991). Oldeman (1998) estimated annual productivity losses averaging 0.1 to 0.2 percent, though considerably higher considering less favorable loss rates and in particular regions (e.g., 0.5 percent per year in Africa and 0.7 percent per year in Central America). Pagiola and Bendaoud (1994) estimated productivity loss rates of 0.4 to 0.7 percent annually on steeper slopes in Morocco, while Pagiola (1996) estimated substantially higher impacts of erosion on maize and beans yields in the Machakos district of Kenya (2.2 percent annual losses). Based on case studies in Africa, Lal (1995) estimated annual yield losses for major food crops (cereals, pulses, roots and tubers) due to erosion in Africa to be between 1970 and 1990 to average 0.5 percent, and 0.3 percent in sub-Saharan Africa. For China, Huang and Rozelle (1995) estimated that environmental degradation, mainly soil erosion and salinization, reduced grain yields by about 0.4 percent per year on average between 1976 and 1989, although the impacts varied substantially by crop and region. For the United States, Pimentel, et al. (1995) estimated annual losses due to soil erosion of 8 percent, but this figure has been criticized by Crosson (1995b) and others. Crosson's own estimates (1986) imply annual losses in the United States of only about 0.1 percent for maize and less for other crops; similar to findings of other studies (Pierce, et al. 1983; Alt, et al. 1989). Using data from an exhaustive review of published experimental studies, Weibe (2003) found that mean yield losses due to soil erosion are usually in the range of 0.01 to 0.04 percent per ton of soil lost, and generally lower in temperate regions. Based on estimates of potential erosion rates for different crops in different parts of the world, Weibe (2003) estimated average annual yield losses for major crops to be 0.3 percent globally, ranging from as low as 0.04% in Europe to 0.94% in Latin America, and estimated at 0.49 percent for Africa. These figures show that the estimated yield loss due to erosion assumed by Bojö and Cassells (1995) is well within the range of published estimates of erosion induced yield losses, and quite close to other estimates for Africa.

As noted earlier, while the EHRS discussed the issue of re-deposition and estimated its extent, it appears that the effect on yields was considered negligible. On the other hand, based on estimates of re-deposition discussed above and assuming that the productivity impacts are approximately linear within the minimum and maximum soil depth thresholds assumed by Sutcliffe, Bojö and Cassells divide the erosion damage estimates presented by Sutcliffe roughly by two.

Based on Sutcliffe's analysis, a critical depth of 100 centimeters was assumed for all crops concerned. Thus for cases where soil depth exceeds 100 centimeters (which is the case for 69 percent of the total cropland) Bojö and Cassells (1995: 35) assumed that the effect of soil erosion can be disregarded as being negligible in the near term. Even taking a relatively long time horizon they note that for most of these cases the user cost is negligible. The effect of soil loss on crop yield is therefore calculated for only about 30 percent of the cropland.

Bojö and Cassells (1995) modified Sutcliffe's estimates of decreased livestock feed availability due to lower crop yields caused by soil erosion by taking into account the effect of re-deposition.

Cost of nutrient loss (due to burning of dung and crop residues):

Bojö and Cassells (1995: 36) referred to a letter from Sutcliffe in 1994 who reported revised calculations that show the opportunity cost for burning of crop residues to be livestock production forgone, not grain loss. They then noted that given that the focus of their work was on land degradation, we should not concern ourselves with use of crop residues as energy rather than livestock feed and that the removal of residues from land is rational as its value is higher as livestock feed than as fertilizer. They noted that "removal of crop [residues] does not constitute 'land degradation' in a meaningful sense of the word, as it is taken from its best alternative use as livestock feed to be used as fuel." They therefore concluded that crop residues should be taken out of the calculation of estimates of the total nutrient loss.

Bojö and Cassells (1995: 36) noted that the same basic model can be used as the one used by Newcombe and Sutcliffe to reconstruct a scenario using functions that relate dung quantities removed to nutrient content and nutrient loss to crop loss (6 kilograms of crop loss per kilogram N or P).

Price adjustment:

Since Sutcliffe's estimates use 1985/86 as the base year, Bojö and Cassells (1995) converted the effect on crop yields into monetary values in 1994 using average rate of inflation and the retail price index for Addis Ababa.[15]

Economic vs. financial costs:

Bojö and Cassells (1995) did not make a distinction between financial (market) and economic (social or shadow price-based) costs, arguing that such adjustments are of minor importance due to the liberalization of major markets in Ethiopia after 1991.

Discount rate, time horizon and future use of dung and crop residues:

Bojö and Cassells (1995) used a discount rate of 10 percent in their calculations of GDFL and GDCL, noting that it is 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. For computation of GDCL, due to expectation of increased demand in the future partly because of population growth, an annual growth rate of 2.5 percent was assumed for use of dung and residue. Assuming limits to the livestock herd and dung production, and limits to what can be collected and returned to cropland, Bojö and Cassells (1995) imposed a cap of 20 million tons of dung.

B. Main findings

Bojö and Cassells (1995) used the following three economic concepts of costs: gross annual immediate loss (GAIL); gross discounted future loss (GDFL); and gross discounted cumulative loss (GDCL). They used Sutcliffe's (1993) estimates as the best available

[15] Starting from a price per ton of EB 890 in 1985/86, they used an average inflation rate of 2.4 percent for the period 1986-1990 and retail price index for Addis Ababa for January 1991 and May 1994. The figure they arrive at is $890X(1.024)^5X1.428$=EB 1,431.

benchmark. They modified Sutcliffe's (1993) estimates of soil loss rates to an average of about 20 tons per hectare per year (or about 2 millimeters per year). After making some rough adjustments to Sutcliffe's calculations based on the assumptions presented above, their analysis leads to the erosion and nutrient loss figures reported in Table 3.

Soil erosion, which is assumed to affect about 30 percent of cropland, leads to a loss of grain of about 7,000 tons per year. Using EB 1,431 as the price per ton of grain in 1994, the value of grain lost due to soil erosion comes to about EB 10 million. The cost of decreased availability of livestock feed due to soil erosion leading to lower crop yields is estimated at EB 0.8 million in 1994 prices.[16] This means a total current income loss of EB 10.8 million due to soil erosion.

Table 3. Reassessment of land degradation costs (EB million)

	Erosion	Nutrient loss
GAIL	$1X10^1$	$6X10^2$
GDFL	$1X10^2$	n.a.
GDCL	$3X10^3$	$8X10^3$

Source: Bojö and Cassells (1995: 13).

+-*-*

[16] Bojö and Cassells (1995) started from the estimated cost of EB 1 million arrived at by Sutcliffe as a measure of cost of decreased availability of livestock feed due to soil erosion in 1985. This is reduced to 0.5 million as the physical impact of soil erosion could be halved due to re-deposition. This figure is then multiplied by 1.608 to adjust the prices and arrive at the final figure of EB 0.8 million as the cost decreased availability of livestock feed due to soil erosion in 1994 prices.

Based on assumptions presented above the loss due to nutrient breaches is estimated at EB 626 million in 1994 prices. Thus, the total GAIL due to erosion and nutrient loss is EB 637 million[17] which amounts to 3 percent of agricultural GDP[18].

The GDFL due to soil erosion with infinite time horizon is estimated at about EB 108 million. This represents the present value of the loss of productive capacity due to soil erosion over an infinite horizon. As mentioned earlier Bojö and Cassells (1995) noted that the accounting for losses in the future due to nutrient breaches is not strictly parallel to that of erosion losses and hence the nutrient losses should be counted only once.[19]

The concept of GDCL is used as layers of costs are added on top of each other due to the fact that land degradation is a cumulative process— another follows the cost of a year's erosion and nutrient removal. For soil erosion, using a decline in crop yield at the rate of 0.4 percent per year due to erosion, presented above, Bojö and Cassells (1995) project the decline in crop yield 100 years into the future, which they deduct from a hypothetical "without" land degradation scenario. Using prices in 1994 and a 10 percent discount rate, the GDCL is estimated at about EB 3.4 billion (in present value terms).

Computation of GDCL for nutrient breaches is based on assumptions of growth in dung and crop residue use and imposing limits to the amount of dung that can be used. With a discount

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

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

[19] To justify this conclusion Bojö and Cassells (1995: 36) argue that "in circumstances in which the supplies to the available nutrient store ….were higher than the total of both crop removals and the nutrient breach, restoration of nutrient retention should allow full recovery of productivity; however, this does not mean that the crop yield would not have been even higher in year two, had the nutrient loss in year one not taken place. …hence, there could be some lasting impact even if the original level of nutrients is replenished. The impact is not lasting over several years, however, as the nutrient store available in a particular year, if available to plants and used would be absorbed by that year's crop, and hence (largely) removed."

rate of 10 percent, the GDCL for the period until 2100 was a present value of about EB 8.3 billion (Bojö and Cassells 1995: 37).

Bojö and Cassells (1995) noted that their results only illustrate the order of magnitude of the problems due to the high level of uncertainty associated with the data used in the calculations of. A comparison of the GAIL and GDCL measures illustrates both the immediate significance of nutrient breaches and the longer-term cumulative effects of physical soil erosion.

C. Drawbacks

In addition to other problems with data and methodology that also apply to Sutcliffe's work on which Bojö and Cassells' reassessment is based, the issue of re-deposition should be examined more carefully. Assuming that re-deposition reduces the costs of erosion by 50% is an arbitrary assumption. We should note however that Bojö and Cassells did a sensitivity analysis and reasonable variation in the rate of re-deposition did not critically impact the end result. Perhaps more data is needed to take into account the effects of deposition on yield.

3.2. 5. Sonneveld (2002)

Sonneveld (2002) estimated the impact of soil degradation (SD) on agricultural production mainly using two approaches: empirical (non-parametric) and engineering approaches. In the empirical approach Sonnveled estimated the impact of SD on crop yields for dominant cereal crops. The soil degradation data (inventory) was based on the work of UNEP/GRID (1992). In the second approach the soil losses (SD) estimated from combined spatial water erosion models are related to all agricultural production (all crops and livestock). In the following section we discuss each approach separately.

3.2.5.1. Empirical approach

Under this approach Sonneveld analyzed the effect of SD on crop yields for the dominant cereal crops and studied this relationship with the population level and fertilizer use within a map unit. Further, he evaluated the effects of soil conservation and application of fertilizer on future crop yields.

A. Basic assumptions, methods and data

It was assumed that soil erosion by water is the most important form of land degradation. The relationship of SD and production was estimated using a non-parametric (kernel density) regression model for rainfed areas. The value of yield ratio (actual/potential yield) served as dependent variable. The reason for adjustment of the actual yield by potential yield was to correct for agro-ecological and crop-genetic differences. The modeling compared yields in relation to indexes of soil degradation and soil fertility. The data set was cross-sectional and comprised qualitative classifications of soil degradation and soil fertility, mean monthly annual rainfall, slope gradients, altitude, temperature, length of growing period and crop yields of dominant cereal crops. All data were geo-referenced according to 460 polygons (map units) of the Crop production System Zones (CPSZ) (FAO, 1998). These map units correspond to former administrative units in Ethiopia (Aurajas). The above data were overlaid with a map on soil degradation derived from an African continental inventory (UNEP/GRID, 1992). Experts on the region and physiographic zone qualitatively carried out the soil degradation assessment.

According to estimates cited by Sonneveld (and consistent with assertions of the EHRS and Hurni (1988), water erosion is the dominant degradation process in those areas where cereals are cultivated, followed by wind erosion (Table 4). The detachment of topsoil is the most widespread soil degradation characteristic, followed by mass movements that mainly occur on the steep soils of the highlands.

Table 4. Degradation type as a percentage of the total area of the rain fed cropping zone

Degradation type	Percentage of total area
Water erosion top soil	57
Water erosion mass movements	29
Wind erosion	8
Other	3

Source: Hakkeling, 1989 cited in Sonneveld, 2002

B. Main findings

The results were depicted in 3-D graphs (mollifier pictures). The relation found between yield ratio and soil degradation was not very strong. However, the analysis identified the following:

- SD has its major impact on soils of lower fertility and where population levels are low.
- On fertile soils, SD is largely compensated by fertilizer application.
- Many areas, populated by a large percentage of the people, are in a critical state, where fertility loss needs urgently to be compensated by new external impacts and/or soil conservation measures need to be implemented (see below). The most vulnerable areas are in northern Ethiopia.

Further, Sonneveld simulated the impact of soil conservation and fertilizer use on yield by changing SD and soil fertility over a period of 10 years and compared with actual yields. The following three policy scenarios were developed.

1) No erosion controls and without fertilizer application (no control scenario)

2) With soil conservation and no fertilizer use (conservation scenario)

3) No erosion control and with fertilizer (fertilizer scenario)

In doing so the following assumptions were made:

1) SD increases by 2.5 per cent per year or is controlled at its current level by soil erosion control.

2) Soil fertility declines by 2.5 per cent per year or is maintained by fertilizer use at its current level.

In scenario 1 crop yields are projected to decrease by 22% over 10 years at national level compared to the actual yields due to soil degradation and loss of soil fertility. In this scenario the northern provinces of Wollo, Gondar and Tigray contain the real degradation 'hot spots' that mark them as priority areas for intervention. A similar spatial pattern of crop yield losses (20% average nationally) was found in the conservation scenario, indicating that soil conservation alone cannot compensate for the decreasing soil fertility levels. In the last scenario yield decreased by 6% implying that fertilizer use may mask the effect of SD and that fertilizer use alone also does not completely stop the decrease in productivity.

C. Drawbacks[20]

- Lack of quantified soil degradation (soil loss intensity) variable. Soil degradation index was defined as qualitative variable (nil, low, moderate, severe, very severe) for each CPSZ based on the qualitative judgment of experts on erosion hazard. Why Sonneveld did not consider the intensity of soil losses was not indicated in the paper.
- The basis for assuming that SD index would increase by 2.5 percent per year and that soil fertility index would decline by 2.5 percent per year without controls is not clear.

[20] Only general comments are discussed here. More technical comments are annexed in Appendix 2.

- The estimated decline in yields (over 2% per year) due to land degradation is higher than most other studies of erosion-yield relationships (see references cited earlier) and appears inconsistent with assumptions in the subsequent engineering approach used by Sonneveld (discussed below), which appear to imply a productivity decline of less than 1 percent per year.
- It was not clear whether the soil degradation index was developed specifically for cereals or for all land use types of each CPSZ (map units)).
- It was also not clear how the soil fertility variable was defined and hence difficult to comment on it.
- Different conservation types have different effect on soil erosion and production. In the Sonneveld paper the type of conservation measures used in the simulation analysis was not mentioned.

3.2.5.2 Engineering Approach

The first approach was focused on annual cereal crops neglecting perennials and livestock production and the impact of overgrazing on soil erosion. In the engineering approach the impact of SD was evaluated for the entire agricultural sector by combining spatial water erosion models with a spatial yield function that gives an estimate of the agricultural yield in its geographical dependence on natural resources and population distribution.

A. Basic assumptions, method and data sources

It was assumed that soil erosion by water is the most important form of land degradation. Specific assumption for each scenario include: free movement of people and easy access to land within and outside ethnic origin of the farmers (migration scenario), access to technology, infrastructures to sale surplus product generated due to improved technology use and accelerated urbanization (non-agricultural sector activities) to absorb surplus rural labor force (technology scenario) were assumed.

The soil losses were estimated using a combination of three spatial water erosion models: USLE model, expert model and accessible data model. A descriptive comparison of model characteristics and statistical comparison of the predictive power of each model showed that the reliability (applicability) of the models varies in specific areas of the data domain. Given this, USLE model was recommended in areas with low rainfall erosivity, defined as an R-factor of less than 50 and slope gradients that are lower than 2%. The expert model applied for land under rangeland or where silt percentages are lower or equal to 40 % and the accessible data (accDat) model was applied for all other combination of land use or biophysical variables.

The impact of soil loss on agricultural production was estimated as a function of soil fertility and water holding capacity following Kassam et al. (1993) and Batjes (1996). Kassam et al (1993) relate soil loss to the two most important soil productivity characteristics: soil fertility and water holding capacity. Soil fertility depends on nutrient status and the regenerative capacity of the topsoil (Smaling et al., 1997; Stoorvogel and Smaling, 1998). To estimate the impact of soil loss on potential yield, Sonneveld approximated the susceptibility of soil fertility to erosion by classifying soil types of each map units into three groups. These are least, moderate and susceptible soil types, implying productivity reductions of 1, 2, and 7 per cent per cm topsoil loss[21]. Based on Batjes (1996) water holding capacity was related to soil depth, soil type, phase and textural class. Unlike the soil fertility case Sonneveld did not

[21] Sonneveld did not mentioned how he derived these figures. However, these estimates are in the range of productivity impacts cited by Weibe (2003). Assuming soil has a bulk density of 1.3 g/cm^3, one cm of topsoil weighs 130 metric tons. Productivity losses of 1 to 7 percent per cm. of topsoil lost translate to about 0.008 to 0.05 percent per metric ton of soil lost per ha.

report yield reduction figures due to reduced water holding capacity. The production impact of soil loss was expressed as potential yield reduction and a reduction of the area under cultivation. If the potential yield level dropped below 20 per cent of the maximum potential yield, the land was considered unsuitable for production. This threshold value was based on the land evaluation criteria of FAO (1993).

To assess the impact of water erosion on food production in Ethiopia; Sonneveld developed a spatial optimization model that maximizes national agricultural revenues under alternative scenarios (Table 5) subject to the possibilities for the rural population to migrate to other rural areas with better prospects. The same data types and sources as in the empirical approach were used.

B. Main findings

The results of the optimization model showed that in scenario 1 where there is no additional land and water conservation measures are not adopted, total national agriculture remains stagnant. The value of agricultural production per capita plunges from \$372 U.S. in 2000 to \$220 in 2010. In this scenario the average annual production decline controlling for the effects of population growth (which was not reported by Sonneveld) compared to the 2000 level was 2.93 per cent. (Column C of table 5). This is equivalent to losing U\$D 5 billion from the agricultural sector due to land degradation over the period 10-years (2000-2010) with annual average of US\$ 500 million. However, with introduction of soil conservation measures production was projected to increase on average by 0.19 per cent per annum. This contrasts with the simulation analysis carried out in the empirical approach (under the conservation scenario) where yield are projected to decrease on average by 20 per cent over 10 years at national level.

The implications of other scenarios are indicated in Table 5. Other scenarios all assume greater flexibility for migration and/or different technology impact. Soil conservation and migration to other productive areas support a slow growth of agricultural production, but this does not suffice to meet the expected food demand. Allowing trans-regional migration, production in the highly degrades areas is exchanged for production in less degraded sites. A shift to modern technology offers better prospects and moderates the migration, but soil conservation, especially in the long term, remains important. In general, each scenario points to the need for a sustained focus on rural production together with conservation of natural resources. However, a vital agricultural sector will also depend on the accelerated growth of non-agricultural activities as it further alleviates poverty in rural areas, contributing to higher income levels for the total population and, simultaneously, relieving the pressure on the land through rural-urban migration. This study emphasizes the need for a combined conservation investment and infrastructural approach.

C. Drawbacks

- The use of the engineering approach to generate soil losses for each CPSZ may be too general given the diversity of the biophysical variables and land use systems within each CPSZ.
- The data or assumptions used to estimate the degradation – productivity relationship are not clearly stated.
- The type of soil conservation measures used in the simulation was not mentioned. In addition to this, the cost of soil conservation not accounted for in the analysis of the agricultural revenue (neither were these costs considered in the other studies reviewed). This will overestimate agricultural revenue or GDP.

- Prices of production will vary depending on the technology used, population size, season, increasing quality of products, etc. Sonneveld used constant prices, ignoring dynamism of price due to factors mentioned above and others (also not considered in other studies).
- It was not clearly spelled out how livestock production was affected by soil erosion; i.e., whether production loss due to soil erosion (soil erosion may reduce grain yield and grazing land) was included in the analysis.
- The result under the control scenario (with soil conservation investment) where production is projected to increase on average by 0.19% per annum was not in line with the results of the conservation scenario in the empirical approach where yield are projected to decrease 20 per cent.
- Off site effects of soil erosion was not accounted for in the analysis (nor in the other studies reviewed).
- The model considered only soil losses by water erosion. Other forms of land degradation were ignored (as in some of the other studies).

Table 5. Impact of soil degradation on food production: Summary of Scenario Results

Scenario	Soil conservation	Agricultural production (in billion USD; PPP)	Per capita agricultural production: rural population (in USD; PPP)	Average annual production loss (gain) due to soil erosion (as % of AGDP)*
		2010	2010	2010
		A	B	C
1. Stationary	No	12.4	220	- 2.93
2. Control	Yes	17.8	324	+ 0.19
3. Migration				
3.1. Restricted	No	15.9	283	-0.91
	Yes	23.2	412	+3.28
3.2. Free	No	16.9	300	- 0.32
	Yes	24.2	430	+ 3.8
4. Technology				
4.1. Stationary (UN)	No	43.5	773	+ 14.89
	Yes	65.4	1163	+ 27.41
4.2.Stationary (AccUrb)	No	43.5	773	+ 14.89
	Yes	65.3	1661	+ 27.36

Source: Sonneveld 2002 (pp 192) and own calculation.
* This is calculated as the yield difference between year 2000 and 2010, controlling for population growth.

Definition of Scenarios
Stationary: No soil conservation, current technology, continued in-situ population growth (no migration)
Control: Investment in soil conservation halting/reducing decline, continuing in-situ population-growth (no migration)
Migration: Restricted – indicates people movement within their ethnic administrative areas of origin
Free – indicates movement within and across ethnic boundaries (tarns-regional migration allowed)
Technology: Assume better quality produce and higher potential levels of production
UN and AccUrb: Scenario for rural labor force growth: population growth under UN prediction & the accelerated urbanization alternative that presents a higher outflow from the agricultural sector to industrial and service activities.

3.2.6 Woody Biomass Inventory and Strategic Planning Project (WBISPP) (WBISPP 2001a, 2001b, 2001c, 2002, 2003a, 2003b, 2004a, 2004b)

The WBISPP was a project that, among other things, looked into issues of land degradation in Ethiopia. This review is based on reports of the project for several regions of the country prepared in collaboration with federal government and regional government offices of Ethiopia (WBISPP 2001a, 2001b, 2001c, 2002, 2003a, 2003b, 2004a, 2004b). The WBISPP reports dealt with various matters including biomass demand/consumption and supply/production issues. However, given the objectives of this review, we will focus on aspects of the reports dealing with the extent and costs of land degradation. We should note, however, that while the reports cover most of the regions in Ethiopia, with different degrees of completeness regarding land degradation, we have not been able to find a report for Oromia.[22] Since this is a major omission we have not been able to make any conclusions at the national level.

A. Basic assumptions and methods

The basic assumptions and methods applied in the WBISPP are similar to those used by Sutcliffe (1993) with some changes introduced using information made available since 1993. The reports indicate that the main types of land degradation in the regions are erosion of soil by water and biological degradation involving the breaching of soil nutrient cycles (nitrogen and phosphorous) by the burning of dung and residues.

A.1 Soil erosion

Using the Universal Soil Loss Equation (USLE) adapted for Ethiopia (Hurni 1988), soil loss was calculated using the following five sets of factors: erosivity of rainfall, erodibility of soil,

[22] We had access to reports on the following regions/administrative councils: Afar, Amhara, Benshangul-Gumuz, Dire Dawa, Gambella, Harari, SNNP and Tigray. However, we present results only for those regions for which comparable data is available.

slope, slope length, land cover, and land management. Values for these factors were obtained from data sets within the GIS.[23] The extent of soil erosion was classified into as many as eight groups.[24]

It was noted that the greatest impact of soil loss on crop yields was through the reduction in soil depth and thus the water holding capacity of the soil. Using a soil-life model (Stocking and Pain 1983) and “Water Requirements Satisfaction Index” (WRSI) developed by FAO (1983) which relates monthly rainfall, soil water holding capacity and evapotranspiration to reductions in crop yield, critical soil depths at which reductions in crop yields start to occur are calculated. As in Sutcliffe (1993), the concepts of maximum and minimum critical soil depth were used. When soil depth is more than the maximum critical depth erosion does not have an impact on yield. The minimum critical depth is that depth at which crop yields are less than 20 percent of those obtained at the maximum critical depth, and are judged as effectively useless for cropping.

These models were used to estimate the impacts of soil loss by water erosion on crop production. It was noted, however, that since soil re-deposition on cultivated land has not been accounted for, the results are over-estimates of crop production losses. Estimates of annual and cumulative crop production and cultivated land lost are made for the period 2000-2025.

[23] The various reports of WBISPP indicate that the rainfall erosivity factor of the USLE was applied to the 1:2 million map of mean annual rainfall and the soil erodibility factors were applied to FAO soil units identified on the MOA/UNDP/FAO 1:1 million soil-geomorphology map. Slope percentages were derived from a digital terrain model created from the 1:250,000 topographic maps of Ethiopian Mapping Agency. Slope length was assumed to be related to slope angle. The land cover factors were based on the Project’s land use and land cover map.

[24] These groups are: 1) 0 - 3.125 ton/ ha/year (equivalent to 0 – 0.25mm of topsoil removed); 2) 3.125- 6.25 tons/ha/year (0.25 – 0.50mm); 3) 6.25 - 12.5 tons/ha/year (0.50 – 1.0mm); 4) 12.5 - 25 tons/ha/year (1 – 2 mm); 5) 25 - 50 tons/ha/year (2– 4 mm); 6) 50-100 tons/ha/year (4 – 8 mm); 7) 100 - 200 tons/ha/year (8 – 16 mm); and 8) 200 - 400 tons/ha/year (16.0– 32 mm).

A.2 Biological degradation

Based on Sutcliffe (1993) which was updated using dung nutrient contents cited in Lupwayi et al. (2000), one ton of dry dung was estimated to be equivalent to 11 kg. of DAP (P equivalent) or 35 kg. of urea (N equivalent) while 1 ton of crop residues was estimated to be equivalent to 1.1 kg. of DAP (P equivalent) or 11 kg. of urea (N equivalent). Dung for fuel collected from the household's own farmland was estimated for each region.

Estimates of the costs of nutrient breaches were made by converting the amount of nutrient lost into the equivalent in terms of fertilizer which was then converted into the equivalent crop loss. A nutrient-increment coefficient of 5 kg. of cereal grain per kg of nutrient (N) was assumed.

B. Major findings

As indicated above, we are not able to report results at the national level and make comparison of results with other studies as the information available is incomplete. We therefore present the general nature of the results for the regions for which data is available.

B.1 Soil erosion

Estimates of the maximum and minimum critical soil depths for reduction in crop productivity due to soil loss are given in Table 6.

Table 6: Estimated maximum and minimum critical depths for reductions in crop productivity due to soil loss.

Crop	Maximum critical depth (cms)	Minimum critical depth(cms)
Maize/wheat	93	28
Sorghum/pulses	77	22
Teff	91	10

Source: Various reports of WBISPP.

Table 6 shows that the lowest critical maximum soil depth was for sorghum and pulses (77 cm) indicating that these crops are more drought resistant than the rest included in the table. However, the lowest critical minimum soil depth was for teff (10 cm).

For regions for which data is available, the percent of total area for each soil loss class is shown in Table 3A of Appendix 3. The results show that soil loss rates are much higher for cropland compared with the results for other land. The total weight of soil moved in gross and net terms is presented by region in Table 3B of Appendix 3. The net soil loss figures indicate the amount lost after accounting for re-deposition.[25]

Estimates of annual and cumulative crop loss due to soil erosion for the period 2000-2025 are presented in Table 3C of Appendix 3. The reports also include cultivated land lost due to erosion. We note from the results that the cumulative loss is particularly significant due to the irreversible damage caused by soil erosion. For Tigray and Amhara regions crop and

[25] Although net soil loss figures accounting for re-deposition are estimated in the reports, the impacts on crop production are based on the gross soil losses, as noted earlier. It is noted in the reports that these estimates of soil loss are generally much lower than those reported in the Conservation Strategies of the regional states.

cultivated land lost due to erosion in 2000 was estimated to be well 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.

B.2 Biological degradation

Using the methods described above, estimates of soil nutrient loss due to the removal of dung and crop residues and their equivalent in terms of chemical fertilizer and grain production lost are given in Table 3D of Appendix 3. Table 3E of Appendix 3 presents plant nutrient losses and grain production foregone for an average family.

We may also note that a comparison of the cost estimates for soil erosion and nutrient breaches shows that in terms of annual losses the costs of the later are much higher than those of the former, similar to previous findings of Sutcliffe (1993) and Bojo and Cassells (1995). In the long-run, however, one needs to take into account the fact that soil erosion leads to irreversible damages.

C. Drawbacks

C.1 Soil erosion

Due to the similarity between the approach followed by WBISPP and Sutcliffe (1993), the major drawbacks discussed there apply to this work as well. These include the use of the USLE in the estimation of soil loss, and the absence of consideration of re-deposition in the estimation of crop losses due to soil erosion.

C.2 Biological degradation

Here as well, the drawbacks of Sutcliffe (1993) generally apply to this study. Thus, whether or not crop residues should be included in the calculation of crop loss is questionable depending on the opportunity cost. The issue of limited availability to plants of removed nutrients contained in burned dung and residues is also relevant.

4. Comparison of results across studies

In Tables 7 and 8, we summarize the basic assumptions, findings and weaknesses of past studies of the cost of land degradation in Ethiopia. In order to compare the costs of land degradation in Ethiopia with results from other countries, we provide additional information on land degradation estimates of some Sub-Saharan African countries in Table 7, and report the estimated costs as a percentage of agricultural GDP.

The estimated annual costs of land degradation in Ethiopia range from 2% to 6.75% of agricultural GDP. The cost estimated by Sutcliffe (1993) is highest, because he accounted for costs associated with burning dung and crop residues, as well as costs of soil erosion. As mentioned previously, Bojö and Cassells (1995) revised downward Sutcliffe's (1993) estimates of the costs of burning dung and crop residues, as well as reducing his estimates of the cost of soil erosion to account for re-deposition of soil, arriving at an annual income loss estimate of about 3% of agricultural GDP. 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, should not be compared to annual losses or annual agricultural income.

The annual costs of land degradation estimated for Ethiopia are within the range of estimates of the cost of land degradation in several other African countries. For example, Bishop and Allen (1989) estimated costs of erosion in Mali to be 4% to 16% of agricultural GDP using productivity and replacement cost approaches. Bishop (1995) estimated costs of erosion to be 3% to 13% of agricultural GDP in Mali and 17% to 55% of agricultural GDP in Malawi. By contrast, Grohs (1994) estimated the costs of erosion in Zimbabwe to be less than 0.4% of agricultural GDP. It is beyond the scope of the present study to review the methods and assumptions of these other studies. However, this small sample of other studies suggests 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.

There are several problems that are common to many or all of the Ethiopian studies that may have caused significant errors, including the following:

- As discussed earlier, land degradation takes various forms including soil erosion (caused by wind and/or water), 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), all 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. These omissions will tend to cause underestimation of the costs of land degradation. On the other hand, Sutcliffe's estimates of costs due to burning of dung and crop residues likely overstate these costs, since they assume that the plant nutrients available in these organic materials would be readily available to crops and lead to immediate productivity impacts, which is doubtful in many circumstances. Bojö and Cassells (1995) removed burning of crop residues from their cost estimates, but still included the cost of burning dung, although they note the problem of assuming that this would have immediate impacts on productivity.

- All studies admitted the poor quality of their data. Furthermore, in their estimation of soil erosion rates, different studies applied different techniques to compute the soil erosion rate. EHRS applied a USLE-type (though not specifically stated) approach, while Sutcliffe and Bojö and Cassells' reassessment was based on the USLE, developed and adopted to Ethiopia by Hurni. As has been noted, USLE was developed for application to croplands in the United States, and does not account for soil re-deposition. This latter problem tends to overstate the costs of erosion, which only a few of the studies addressed (albeit in an *ad hoc* fashion). Sonneveld applied a combination of approaches (such as map units, USLE and expert and accessible data model), and found that different approaches to estimating erosion were better suited to different conditions. Notwithstanding the limitations of the USLE itself and poor data quality, differences in approaches of estimating soil erosion could possibly explain differences in soil erosion and cost of soil erosion estimates.
- In estimating erosion-yield relationships, different studies made different assumptions concerning the minimum and maximum depth requirements for plant growth which, we believe, will have considerable implications to their estimation of cost of soil erosion. EHRS and SCRP implicitly assume no critical soil depth requirement for plant growth, whereas Sutcliffe constructed a matrix of minimum and maximum soil depth requirements for different crops, which attaches zero value for any level of soil erosion unless the soil depth is below the critical level. Bojö and Cassells assumed a critical depth of 100 cm for all crops, which excludes crop lands with soil depth above 100 cm in their estimation of costs of soil erosion. As a result, Bojö and Cassells estimated the cost of soil erosion only for 30% of the cropland used. This ignores the (possibly irreversible) loss in the capacity of soils that are deeper than 100 cm resulting from erosion, assuming that this is no economic value; possibly tending to

understate the costs of soil erosion. As noted in earlier in this paper, in the context of uncertainty, loss of deeper soils may entail a loss of option value associated with the ability of the soil to buffer against unforeseen adverse events in the future.

- With the exception of Bojö and Cassells, none of the studies distinguished soil loss as an immediate loss, a future loss and cumulative losses to the national economy. EHRS and Suttcliffe reported the discounted future loss, whereas SCRP and Sonneveld reported only immediate losses. It is only in Bojö and Cassells that all the three types of costs were clearly reported. Thus some of the estimates reported in different studies are not comparable.
- The soil erosion rates imputed in many of the studies, with the exception of Bojö and Cassells, did not take re-deposition of soil into account. Even their inclusion of re-deposition was based on a crude assumption (a 50% re-deposition rate and a reduction of 50% of the productivity losses as a result) and an even distribution of re-deposited soil across crop lands. The actual effects of re-deposition of soil on downstream productivity are far from clear. Thus, it is difficult to say whether the reassessment conducted by Bojö and Cassells leads to an overestimate, an underestimate, or a reasonable estimate.
- In all of the studies the benchmark levels of soil erosion and nutrient balances were not clearly specified. This makes comparisons of estimates across studies difficult. Furthermore, the discount rates and the time horizon used to impute value to cost of soil erosion differ across the studies, also making comparisons difficult.
- Price dynamics were not considered in any of the studies, with the exception of Sonneveld who arbitrarily assumed a 2.5% annual growth in soil erosion and 2.5% annual soil fertility decline. All the costs of soil erosion were computed with a constant price and soil erosion rates over the years. The impacts of land degradation

on prices were not considered. Since land degradation tends to reduce agricultural supply and hence increase prices of commodities (if not perfectly tradable), this would tend to reduce the costs of land degradation to farmers but increase it for consumers as a whole. Of course, the costs to particular farmers and consumers likely vary greatly, depending on their net sales or net purchases of commodities, the extent to which they are affected by land degradation, and other local factors.

- Almost all studies did not indicate how they aggregated their estimates to national or regional levels. Significant problems of aggregation could have resulted from the fact that the relationships between land degradation and productivity are nonlinear, and estimates basically represent averages of conditions at the lowest unit of aggregation used in each study. To the extent that threshold effects are present, costs could be substantially underestimated or overestimated as a result of averaging degradation processes and productivity impacts over large spatial units.
- As can be verified from FAO data on production and land use patterns in Ethiopia, we don't observe as much decline in cropland use, crop production, or yields in Ethiopia over the last 20 years as predicted by some of the studies (see Figures 1, 2 and 3). For example, the area of cultivated cropland has not changed to a large extent since 1993, contradicting the dire predictions of the EHRS and Sutcliffe that large areas of cropland would be abandoned by 2010 (see section 3.2.1. B.1 and table 2). Cereal yields have also 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 4), which might be in part a response to soil nutrient depletion and may be masking negative effects of soil erosion. This seems consistent with Sutcliffe's, Bojo and Cassells' and Sonneveld's assessments of soil fertility depletion as a major form of land degradation in Ethiopian highlands.

It is impossible to say without a more detailed study whether the errors in the available studies have caused them to over- or underestimate the costs of land degradation on balance, since some of the errors tend to overestimate land degradation impacts and some tend to underestimate them. 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 agricultural GDP. Of course, there are large differences in the estimated components of those costs, since several of the studies focused only on soil erosion, while those that focused on soil nutrient depletion due to burning of organic materials found that this has 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 (if they ever could be known with confidence) are likely to be of the order of magnitude of the range of estimates shown in Table 8; i.e., a few percent of agricultural GDP per year.

Table 7: On-site cost of soil erosion estimates from Ethiopia and other Sub-Saharan African countries.

Authors	Method used to compute soil erosion rate	Approach used to quantify erosion-yield relationship	Methods used to evaluate cost of soil erosion	Discount rate and (time horizon)	On site cost of soil erosion (% of AGDP)	Measure of cost
EHRS, 1986	USLE-like approach (not clearly specified)	No formal model but guesstimates based on international estimates	Change of productivity (CP)	9 (25 years)	2.2	Annual average of cumulative costs over 25 years (similar to GDFL)
SCRP, Hurni, 1988	USLE: modified for Ethiopian conditions	Experimental observations (52 sample plots of barley production)	CP	Only immediate losses are computed	2 (Bojö & Cassells, 1995)	Annual decrease in productivity
Sutcliffe, 1993	Used estimates from Hurni (1988). In addition to soil losses, nutrient losses from residues & dung was considered	Soil life model of Stocking & Pain (1983)	CP	Discount rate: not reported Time horizon: 25 years.	6.75 (including loss due to erosion & burning of dung and crop residues)	GAIL of nutrient losses, plus GDFL of erosion losses (GDFL < 1%)
Bojö & Cassells, 1995	Same as Sutcliffe	Followed approach of Sutcliffe, but adjusted for assumed effects of re-deposition of soil	CP	10 (100)	3 (including loss due to erosion and burning of dung)	GAIL and GDFL (GFFL < 1%)
Sonneveld (2002)	Empirical approach(EA): Map units based on UNEP/GRID, 1992 and for engineering approach(ENA) USLE, Expert and Accessible data models	EA: Non-parametric regression model & graphs where yield expressed as function of soil degradation index, ENA: calibration (empirical) relations. Yield reduction specified as a function of loss of soil fertility & water holding capacity within each map unit. Soil fertility classified into three based on their susceptibility to erosion and percentage of yield reduction assigned for each class. Similarly water-holding capacity was related to other soil characteristics.	CP	Not indicated (10 years for EA and 10 & 30 years for ENA but we consider 10 (2000 to 2010 to be comparable to other studies)	2.93	
Stocking, 1986; Zimbabwe	Not clear[a]	NA	Replacement cost (RC) of lost nutrients	NA	9	GAIL
World Bank, 1988; Madagascar	Not clear[a]	Expert judgement	Not clear[a]	NA	<1	GAIL
Bishop and Allen, 1989; Mali	USLE	Inferred erosion yield decline function	Both change of productivity (CP) and RC	10 (10 years)	4 to 16%	GDFL
Convery and Tutu, 1990; Ghana	Not clear[a]	NA	RC		5	GAIL

Authors	Method used to compute soil erosion rate	Approach used to quantify erosion-yield relationship	Methods used to evaluate cost of soil erosion	Discount rate and (time horizon)	On site cost of soil erosion (% of AGDP)	Measure of cost
Ehui et al., 1990; Western Nigeria	SCIAF in combination with experimental results	Regression analysis relating maize yield to cumulative soil loss	CP	10 (20 years)	-	
Bojö, 1991; Lesotho	Not clear[a]	Multiple regression analysis relating yields of major crops to estimated erosion rates across districts	CP	Not clear[a]	5	GDFL (GAIL < 1%)
Norse and Saigal, 1992; Zimbabwe	Not clear, but builds on Stocking's (1986) work	NA	RC	NA	8	GAIL
World Bank, 1992; Malawi	Soil Loss Estimation Model for Southern Africa (SLEMSA)	Exponential yield decline model based on Lal (1987), using assumed range of yield decline coefficients	CP	10 (10 years)	18	GDFL (GAIL = 3%)
Pagiola, 1993; Kenya	USLE	Linear regression	CP	10 (100 years)	-	
McKenzie, 1994; South Africa	Expert judgment	Expert judgment	CP	Not clear[a]	4 (all major forms of land degradation)	GDFL (GAIL < 1%)
Grohs, 1994; Zimbabwe	SLEMSA	Plant growth simulation models EPIC and CERES; inferred erosion yield decline function	CP	0, 10, 15 (50 years)	0.36%	
Bishop, 1995; Mali and Malawi	USLE	Regression analysis relating yields to cumulative soil loss	CP	5, 10, 15 (5, 10, 20 years)	Mali: 3-13% Malawi: 17-55%	
Eaton, 1996; Malawi	Relies on data of earlier studies from other countries	Combines existing data with adopted data from Ehui et al., 1990	CP	5, 10, 15 (10, 20 years)	3%	

Source: Adapted from Enters (1998), Bojö (1996) and this review.

[a] For studies other than those reviewed specifically for the present study, Table 7 relies on descriptions of the methods provided by Bojö (1996) and Enters (1998) (i.e., no attempt was made to review the studies cited by these authors for other African countries.

Table 8: Basic assumptions, weaknesses and estimates of past studies of production losses due to erosion in Ethiopia

Authors	Assumptions	Comments	Reported on site cost of soil erosion for the highlands	Our computation of on-site costs (as % of AGDP) for the highlands. (AGDP, ETB 7.4 bn (1985))
EHRS	• Only erosion by water considered. • Constant base price • Constant soil erosion rate over time assumed. • No change in agriculture productivity assumed. • Even distribution of redeposited soil across crop lands assumed.	• Yield reduction estimates based on "guess estimates" using the international evidence reviewed. • No down stream (off-site) costs estimates. • Agricultural Market Price, which is 20-30% lower than the then market price used. • Not obvious how re-deposition was estimated. • No bench mark of soil erosion specified. • Admitted poor data quality	• 2.2% of agricultural production	• 2.2%
SCRP, Hurni (1988)	• Only erosion by water • Original soil depth > 50 cm and rooting depth > 100 cm assumed • Constant price and constant soil erosion rate over time was implicitly assumed	• Results based on experimental data which was not validated with field data. Hence poor data quality admitted. • Yield loss of soil erosion estimated from 52 sample barely plots • No down stream (off-site) costs estimates • Only immediate soil loss estimated. The cost of cumulative soil loss not estimated. • No rediposition considered. • No bench mark of soil erosion specified except original soil depth was assumed to be 50mm for all crop lands which is again crude. •	• 2% of agricultural production (reported in Bojö & Cassells)	• 2%
Sutcliffe (1993)	• Erosion by water and nutrient losses due to removal of dung and crop residues considered. • Erosion rates based on Hurni's estimate but productivity loss was estimated using soil life model and nutrient breach models, which assumes the required soil depth as being crop-specific which is a more refined assumption than that of EHRS and SCRP assumptions of equal depth requirement for all crops. • Used constant market prices in 1985/86. • Perfect substitutability of chemical fertilizers to dung/residues assumed.	• Erosion estimates borrowed from Hurni. Hence all limitations of Hurni's soil erosion estimates apply here as well. • No rediposition considered. • No down stream (off-site) costs considered. • No bench mark of soil erosion specified • Admitted poor data quality	• Soil erosion + nutrient losses + livestock loses= EB 581 mn in 1985.	• 7%

Authors	Assumptions	Comments	Reported on site cost of soil erosion for the highlands	Our computation of on-site costs (as % of AGDP) for the highlands. (AGDP, ETB 7.4 bn (1985))
World Bank (Bojö & Cassells, 1995)	• A critical depth of 100cm assumed for all crops. As a result only 30% of the crop lands considered. • 50% re-deposition rate assumed. • Crop redidues out of calculation as its use as livestock feed has high value than fertilizers and hence not considered as part of cost of land degradation. • Adjusted Sutcliffe's 1985/86 price to 1994 price using average rate of inflation and A.A. CPI. • Dung production grows at 2.5% per annum. •	• 3 concepts of soil losses considered (GAIL, GDFC, and GDCL) • Crude estimate of re-deposition • No down stream (off-site) costs considered • No bench mark of soil erosion specified • Admitted poor data quality	• GAIL: 3% of AGDP	• GAIL: 3% of AGDP •
Sonneveld (2002)	• Constant base price • Only erosion by water • Each map units classified into three groups of susceptibility of soil fertility to erosion. These are least, moderate and susceptible soil types, implying productivity reductions of 1, 2, and 7 per cent per cm topsoil loss. • Specific assumptions (free movement of farmers within & outside their ethnic origin, easy access to technology, infrastructures & land, constant population growth) • Empirical approach: Soil erosion is assumed to grow by 2.5% per annum or controlled at its level by soil erosion control. With this scenario, yield declines by 22% at national level due to soil degradation and fertility loss. Similarly, soil fertility is assumed to decline by 2.5% per annum or is maintained by fertilizer use at its current level. With this scenario, yield declines by 6% implying use of fertilizer masks though does not fully stop the decline in productivity.	• All estimates are at the national level (not specific to the highlands). • No re-deposition considered • No down stream (off-site) costs considered • It was not mentioned how he reached into three classification of susceptibility of soil fertility to erosion. • No bench mark of soil erosion (soil fertility) level specified. • With the control scenario, the type of soil conservation not specified. • Inconsistency between the empirical and engineering approach estimates.	• Loss of ETB 5 bn from 2000 to 2010,with no conservation	2.9% (with stationary scenario)
WBISPP (2001-2004)	• Same as Sutcliff (1993)	• Same as Sutcliff (1993)	• No national level estimates	No national level estimates

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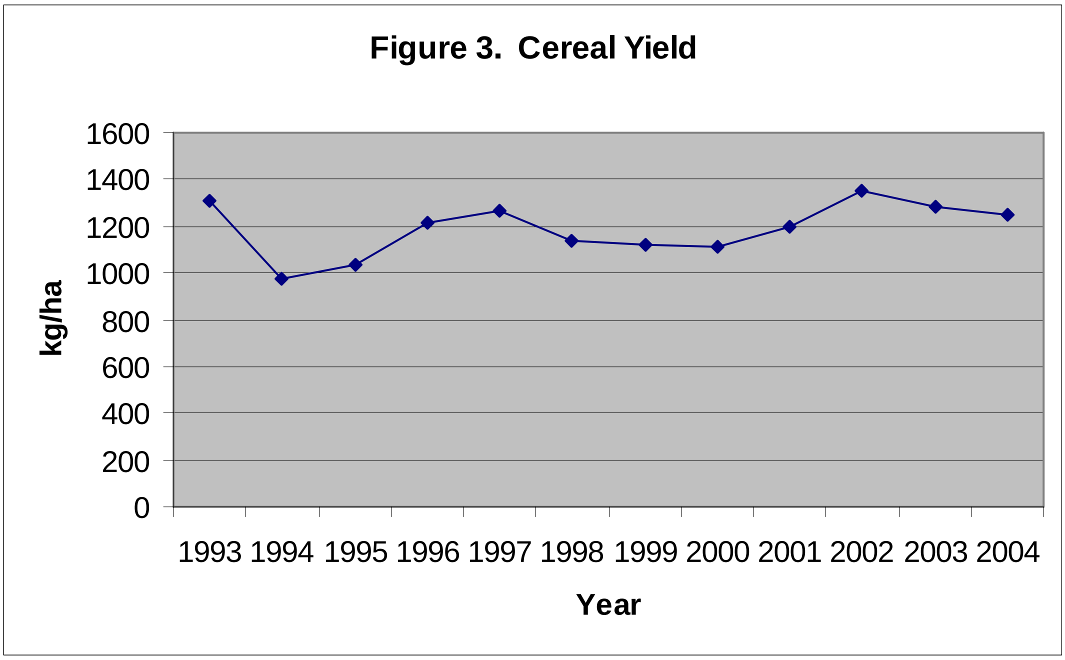
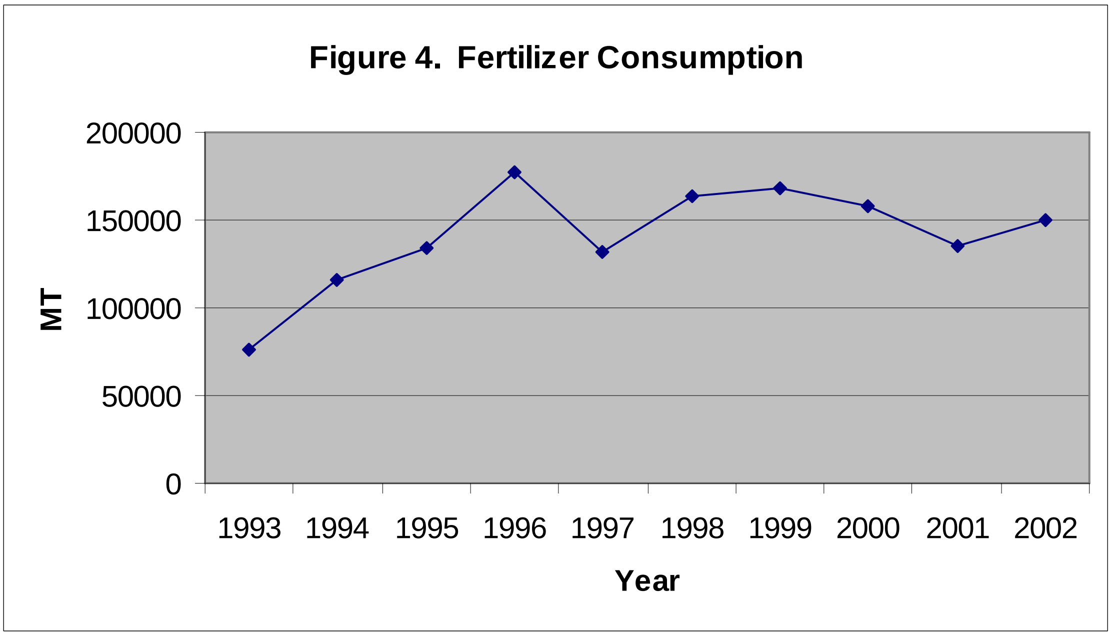
Source: FAOSTAT, 2005



Source: FAOSTAT, 2005



Source: FAOSTAT, 2005

5. Conclusions and implications

Although there has been considerable effort in the last few decades to estimate the on-site costs of land degradation in Ethiopia, our review suggests that each 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 on the order of a few percent of agricultural GDP per year—though not as dire as some may believe.

This is not to say that the problem is not severe in many areas. Some of the studies highlight particular land degradation “hotspots”, such as large areas of Tigray, Wello and Gonder, as emphasized by Sonneveld’s findings. Furthermore, Sonneveld’s 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 of severe degradation occurring in some very high potential areas, likely lead to high costs of land degradation per hectare in such areas. For example, Gete and Hurni (2001) found that their study area (Dembecha watershed in a high potential area of Gojjam) lost 3% of its total land area between 1957 and 1995 due to land degradation, and 5% of the area reached critical soil depth (i.e 25cm and below). They also predicted an additional 21% of the currently cultivated land will reach critical soil depth over the coming 15 to 47 years. Similar problems high rates of land degradation and negative productivity impacts have been noted in the Ginchi watershed near Holetta in the Oromiya region (Okumu, et al. 2002); Andit Tid watershed in north Shewa (Shiferaw and Holden 2001); and other high potential locations in Ethiopia (e.g., Lakew Desta, et al., 2001; and Bezuayehu Tefera, et al., 2002).

Some of the more recent studies emphasize the problem of soil fertility depletion as being at least of equal 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 (various years) are fairly persuasive that the costs of erosion are probably less than earlier thought while the importance of soil nutrient depletion is more important. This finding is supported by Sonneveld's (2002) findings from his empirical study and actual production and yield data since 1985. But we also think that Sutcliffe's and Bojö and Cassells' approaches to estimating costs of burning organic materials overstates those costs, since the usefulness of these organic materials as a fertilizer are probably less than assumed in many cases, due to loss of nitrogen from manure, difficulties of applying manure on distant plots, etc. So our sense is that the on-site costs of these types of land degradation may be still less than Bojö and Cassells estimate. Nevertheless, there are still other aspects of land degradation that haven't 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.

For future research, we think the key gap is the need for 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. That requires investigating off-site effects where those 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, particularly where water resource development is taking place. Further research is needed to address this topic. We recommend that such research focus on areas where valuable downstream resources are most at risk due to land degradation upstream.

To define what the government's and other stakeholders' roles should be, it is also important to consider the difference between private and social costs and returns. If private net present values are high for conservation investments, opportunities for adoption may be great, though market imperfections and constraints such as land tenure insecurity or credit constraints may need to be addressed for adoption of sustainable land management practices to increase. If social returns are high but private returns are low, a more active approach involving subsidies, taxes or regulations may be necessary to ensure socially optimal levels of investment. By contrast, if both social and private returns are low, there is no efficiency rationale to promote investments, unless these returns can be increased by improving the technologies and/or the market environment. In such cases, alternative livelihood options may be more effective to address land degradation problems where they are severe.

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Appendix 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. **1.** Gross annual immediate loss (GAIL): This is the loss of gross agricultural output in a single year due to land degradation in the same period of time. The comparative format is generally if no land degradation took place. The concept is “gross” because it does not account for (1) the cost of combating land degradation or (2) any cost reductions related to lower production.
2. **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/r. This concept does not apply to nutrient losses.
3. 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 on top of each other. This concept also applies to nutrient breaches as there will be a stream of GAILs probably increasing due to population growth and mounting scarcity of wood fuel.

Appendix 2: Technical comments on Sonneveld's (2002) work

1. Empirical approach

- ♦ The production function specification (particularly specification of the explanatory variables) is incomplete, as they do not include at least the traditional production inputs (labor, fertilizer, soil conservation, etc), likely leading to omitted variable bias. Given the average number of observations (map units) of 8.8 per administrative area, it would have been possible to use fixed effects (dummy variables for Aurajas), which would have helped to control for omitted variables. The dependent variable is specified only as a function of the SD index and soil fertility and was adjusted by the potential yield assuming that this captures actual yield variations due to agro-ecological and crop-genetic differences. However, this specification may only correct for inter-CPSZ differences but will not capture intra (within) CPSZ variations due to variations in agro-ecological, crop genetic traits, cropping pattern, infrastructure, population density, landforms, land use and management that lead to yield and soil degradation variation within each CPSZ, leading to aggregation bias.
- ♦ Another problem related to the specification of the dependent variable was the price used to convert physical yield into monetary values. The years where the yield observations were taken (mid 1980s to 1995) and the prices (average of 1993 and 1994) used to convert physical yield into value do not coincide.

2. Engineering approach

- ♦ The specification of the dependent variable was the same as the empirical approach and thus the engineering approach encountered the same problem. The weighting of livestock production only by grazing lands assuming livestock feed source is only grazing lands overestimates livestock productivity and carry capacity of grazing land since the author ignored livestock dependence for feed on cultivated land (straw and stubble).

- In the yield function only labor input (population in each CPSZ dived by potential yield per ha times total area of cultivated land) was considered. First, this is a crude representation of labor, as it does not differentiate rural labor into active and non-active labor. Secondly, it is also not clear why the population in each CPSZ after correcting for urban population is divided by total potential production in order to derive the labor input, which is different from the traditional ways of specifying labor (labor per ha). Thirdly, input variables such as conservation inputs and agrochemical are not included in the yield function.
- It was not clear which input costs were considered in the optimization model.
- Sonneveld used a production function (Mitscherlich-baule function) different from the familiar production functions. It's not clear how well this model specification fits the data; no specification tests reported or alternative specifications considered.

Appendix 3. Estimates of soil loss, nutrient losses and crop losses due to land degradation by WBISPP

Table 3A Soil erosion classes by region (mm or tons/ha/year removal of soil)

Area covered	Region	<0.25mm <3.125 tons	0.25-0.5 mm 3.125-6.25 tons	0.5-1.0 mm 6.25-12.50 Tons	1.0-2.0 mm 12.5-25.0 tons	2.0-4.0 mm 25.0-50.0 Tons	4.00-8.00 mm 50.0-100.0 Tons	8.0-16.0 mm 100-200 tons	16.0-32.0 mm 200-400 tons
Percent of total area of region	Amhara	63%	10%	9%	8%	6%	3%	1%	0%
	Beneshangul-Gumuz	88%	5%	4%	1%	1%	0%	0%	0%
	SNNP	37%	4%	19%	26%	3%*			
	Tigray	77%	7%	8%	6%	2%	1%	0%	0%
Percent of region's cultivated land	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%

*This figure applies to 25-200 tons of soil loss class

Source: Various reports of WBISPP.

Table 3B Gross and net soil loss by region in millions of tons per year

Region	Gross soil loss	Net soil loss*
Amhara	147	25
Benshangul-Gumuz	5	0.8
Tigray	27	5

*Net soil loss is gross soil loss less soil re-deposited within the landscape.

Source: Various reports of WBISPP.

Table 3C Estimated annual and cumulative reductions in crop production (tons of grain) 2000-2025 due to soil loss on cultivated land within the critical soil depths by region

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: Various reports of WBISPP.

Table 3D **Estimated loss of crop nutrients due to the burning of crop residues and dung in tons**

Region	Crop residues		Dung		Total Urea	Total DAP .	Grain production foregone
	Urea equiv. (N)	DAP equiv. (P)	Urea equiv. (N)	DAP equiv. (P)			
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
SNNP					14580	1458	41621
Tigray	1,277	128	9,263	2,911	10,541	3,039	24,112

Source: Various reports of WBISPP.

Table 3E **Estimated on-farm plant nutrient losses due to the burning of crop residues and dung (kg per farm*)**

Region	Crop residues		Dung		Total Urea	Total DAP	Grain production foregone
	Urea equiv. (N)	DAP equiv. (P)	Urea equiv. (N)	DAP equiv. (P)			
Amhara	10	1	26	8	32	8	73
Beneshangul-Gumuz	3.5	0.4	0.32	0.1	8.04	0.87	18
Tigray	3	0	20	6	23	7	52

*A farm here is defined as a farm family.

Source: Various reports of WBISPP.